Arnold Schwarzenegger
Governor

MAINTAIN, ENHANCE AND IMPROVE RELIABILITY OF CALIFORNIA'S ELECTRIC SYSTEM UNDER RESTRUCTURING

APPENDIX - XI

Development of Path 15 Software

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:

Lawrence Berkeley National Laboratory

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Development of Path 15 Software

Managing Power Transfer Constraints on a Major Transmission Interface: Path 15 of the California Transmission System With EPRI's DTCR Technology

1009280

Final Report, December 2003

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PRODUCT DESCRIPTION

In a previous research project, a dynamic thermal software model was developed and tested for the California Path15 power transmission interface. A summary of that work is included in this report. The dynamic thermal model used real-time data from tension monitors on the critical Gates Panoche 230-kV lines. It also used continual updates of an automatic load and generation reduction scheme to calculate the post-contingency Path15 power flow resulting from the loss of two 500-kV lines (double line outage DLO) that are part of the interface. The Path15 model incorporates the PG&E load reduction scheme and the manual reduction of generation from Diablo Canyon nuclear plant. In this project, the original software model has been extended to include the Gates 500-/230-kV power transformer that also is a critical part of Path15.

Results & Findings

As a result of this project, the real-time dynamic thermal rating of the Path15 transmission interface could be provided to the system operator to guide generation dispatch decisions during critical periods. In doing this, however, other limits on power flow through the Path15 interface need to be considered. These include, but are not limited to, the power flow limits on the series capacitors on the 500-kV lines and certain voltage and stability operation limits. Nonetheless, the anticipated result allows increased Path15 power flow under favorable conditions and limits Path15 power flow under unfavorable conditions so that major system components are not damaged in the event of the proposed contingency.

Path15 is probably the most complex transmission interface in the California transmission system. Successful development and field-testing of this dynamic Path15 model strongly suggests similar dynamic models can be developed for other less complex transmission interfaces. It appears that developing these dynamic models requires (1) system analysis to define power flow relationships (distribution factors) and impacts of load and generation reduction events, (2) installations of line and power transformer monitors and communication links from remote locations to a server through supervisory control and data acquisition (SCADA), (3) development of a real-time software “shell” that calculates pre- and post-contingency loads on critical interface components, including iterative calculation of interface rating, (4) inclusion of previously developed and tested thermal model algorithm objects such as the EPRI Dynamic Thermal Circuit Ratings (DTCR) library, (5) inclusion of off-line power flow limits reflecting concerns about voltage and stability limits, and (6) economic trade-off analysis. The greatest difficulty using the Path15 dynamic rating model is the variability of power transfer thermal and stability limits and the limitations this places on the system operator’s ability to use the results. The need for load forecast and real-time rating predictions needs to be incorporated in both Path15 and other interface applications. Beyond forecasting challenges, additional business implementation challenges involved in extending the use of dynamic interface modeling include (1) analyzing dynamic rating equipment, component failures, and their impacts on transmission system operation, (2) assessing operational procedures, protocols, and information exchange required between owners and operators, (3) determining equipment redundancy, accuracy, and maintenance procedures and requirements, (4) locating lines and substation components that are thermally limited to gain more actual experience with these tools, (5) incorporating voltage and system stability limits into the dynamic models, (6) determining processes and procedures so transmission owner/operators and ISO/RTO's can use this tool in dealing with markets and in contingency management situations, and (7) analyzing future changes to system capacity or configuration that may impact the operational or economic need and viability of the technology. The Path15 dynamic modeling project serves as a prototype model for managing complex transmission interface power flow with state-of-the-art technology.

Challenges & Objectives

This report describes development of dynamic thermal models for a complex transmission interface that should benefit transmission system planners, equipment engineers, and system operators. Through the application of monitoring instruments and complex numerical models, study results allow increased power flow and increased system reliability. The computer models developed for Path15 should be extended to other simpler power system interfaces and include non-thermal limits on power transfer.

Applications, Values & Use

EPRI has developed sophisticated dynamic thermal rating technology that has increasing application as the North American power transmission system evolves. This project demonstrates how previously developed, self-contained software objects like the DTCR thermal model library can be used both to improve the quality of engineering models and to save time and money by avoiding the need for basic model development.

EPRI Perspective

EPRI is on the cutting edge of dynamic thermal modeling of power equipment. The institute's available numerical thermal models offer a unique opportunity for members to develop complex models with minimal programming and testing.

Approach

The project team adapted a sophisticated power transformer thermal model algorithm ("PTLOAD" developed by EPRI as part of the DTCR technology package). By taking this approach, the team avoided development and extensive testing of a new power transformer thermal rating algorithm, modeling the interface in minimal time at minimal cost. When calculating the Path15 dynamic thermal rating, the team's model can take into account a double line outage (DLO) where both 500-kV lines are suddenly taken out of service. In such an event, the current in the Gates-Panoche 230-kV line and in the Gates 500/230-kV transformer, which supplies power to this overhead line, are limited. This prevents violation of electrical clearance minimums, and the hot spot temperature is limited to avoid bubble formation and excessive loss-of-life of the transformer insulating material.

Keywords

Dynamic thermal circuit ratings (DTCR)	Path15	Complex transmission interface
Remedial action (load shedding)	Line tension monitors	Loss of insulation life
Winding and hot spot temperatures	Effectiveness factors	Thermal model libraries

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1 PROJECT GOALS

California's PATH15 interface consists of four 230kV lines, two 500 kV lines, autotransformers at the Gates substation feeding power to the 230kV lines, and numerous other transmission and substation equipment. The power flow through PATH15 is limited such that, if both 500 kV lines are suddenly taken out of service (a "double line outage" or "DLO"), the remaining lines and transformers will not be overloaded.

A previous California Energy Commission (CEC) funded research project (see Appendix B) developed and tested custom software to calculate the dynamic PATH15 thermal rating on the basis of real-time data for the critical Gates-Panoche 230 kV overhead line (the most heavily loaded 230kV line during the DLO). The goal of the present project is to extend the previously developed dynamic PATH15 rating software to include consideration of the real time thermal rating of the Gates 500/230kV power transformer by linking the power transformer rating model in EPRI's Dynamic Thermal Circuit Rating (DTCR) software to the existing program.

EPRI has developed sophisticated software for the thermal rating of power equipment – overhead lines, underground cable, power transformers, and other substation equipment. The Power Transformer Loading program (PTLOAD) was developed for utility engineers and planners to perform thermal rating calculations for power transformers. DTCR is intended for use by transmission operations and maintenance personnel to dynamically rate entire transmission circuits (including power transformers) on the basis of real-time System Communications and Data Acquisition (SCADA) data. The underlying power transformer thermal algorithm ("Common Calculation Algorithm"), used in both software applications, is based on IEEE Standard 57.92-1995 and on IEC Standard 357. Field test results at several locations have revealed that power transformers can be safely operated at higher power levels if ratings are based on real-time air temperature and loading rather than on worst-case conditions. These tests also indicate that routine monitoring of transformer temperatures and cooling equipment operation is crucial to safe operation.

In the present project, the thermal model algorithms of the EPRI DTCR software have been adopted and linked to the existing PATH15 real-time rating software. This has increased and widened the capability in dealing with Path15 power flow limits this development was done re in cooperation with Pacific Gas & Electric. PG&E operations personnel who have direct access to real-time transformer temperatures, loads, and cooling equipment function supported the initial application and verification of the modified software.

2 ADOPTION BACKGROUND

EPRI's Power Transformer Common Calculation Algorithm (PTCCA) calculates transformer temperatures, ratings, loss of insulation life, and gas bubble formation based on user-specified physical parameters for the transformer and user-specified load and air temperature data. Four temperature calculation algorithms are available in the PTCCA: the "top-oil"; "bottom-oil"; "IEC"; and the "PAR" phase angle regulating transformer models.

When linked to the PTLOAD 5.1 application software, the user-specified load and air temperature input data is either a daily load/ambient pattern (for "Design" mode) or a chronological file of load/ambient of any length obtained from field monitoring (for "Planning" mode).

EPRI's thermal modeling software

EPRI's DTCR software allows real-time thermal rating calculations for overhead lines, underground cables, and power transformers. A similar but slightly earlier power transformer algorithm (PTCCA3) is incorporated into the present EPRI DTCR2.1 product. The thermal model library algorithm in DTCR (called "TML3") includes models for overhead lines, power transformers, and underground cables. DTCR uses input data from real-time SCADA/EMS sources to calculate the dynamic or real-time thermal rating of series combinations of transformers, lines, and underground cables.

The power transformer thermal algorithms in both PTLOAD and DTCR are based on IEEE Standard C57-91-1995 and IEC Standard 354 but differ slightly in software details. Physical parameters including the transformer voltage, insulation loss-of-life constants, top oil and hot spot winding temperature rises, and the user must specify load/ambient cycle data after a review of manufacturer certified test reports.

The "top oil" calculation, available in both PTLOAD and DTCR, assumes a single bulk oil temperature and is widely used in the United States for transformer rating calculations. More recently, experimental investigations have shown that the more complex "bottom oil" model (also included) may provide a better indication of the transformer hot spot during times of rapid change in electrical load. Either algorithm can be used if suitable data is provided.

All the present EPRI power transformer calculation models include the following features:

- Ability to define multiple cooling stages and either has automatic switching or manual operation.
- Single or balanced three phase units are supported.

- Recognizes limits on top oil temperature, winding hot spot temperature, insulation loss of life, and bubble formation.

3
IMPACT OF PATH15 OPERATING ACTIONS ON TRANSFORMER LOADING

The limit on power transfer through Path15 is determined such that:

- no elements will be overloaded following the loss of both 500 kV lines ("DLO")
- the WECC Interconnection remains transiently stable
- the Fresno local area voltage does not collapse
- WECC Planning Criteria is not violated, specifically including the voltage deviations.

Depending on operating conditions, the limiting element following the DLO may be the Gates-Panoche 230kV double circuit line, the Gates 230/500 kV power transformer, and/or certain other elements. A previous project, funded by the CEC, installed line tension monitors on the Gates-Panoche 230kV lines to allow real-time rating but assumed that the thermal rating of the Gates 500/230kV power transformers was unvarying. The present project involves extending the existing software by replacing the fixed rating of the Gates power transformer with a dynamic thermal model.

The rating of the PATH15 transmission interface can be determined by a number of system concerns including but not limited to the power flow limits on the series capacitors on the 500kV lines and the maximum operating temperature of the Gates Panoche 230 kV line after a DLO. The inclusion of a dynamic thermal model for the Gates 500/230kV power transformer only affects the Path15 rating at those times when this transformer is at or near its thermal limit. The anticipated result is to increase the PATH15 power flow limit under those circumstances and allow additional power to be imported into Northern California during critical times.

The loss of both 500kV lines is a relatively rare contingency event. Nonetheless, the power flow through this path is normally limited such that the post-contingency power flow in the 230kV double circuit line from Gates to Panoche does not cause a clearance violation. With the addition of EPRI's DTCR software to the present PATH15 software, the pre-contingency PATH15 power flow is calculated such that neither the Gates-Panoche 230kV line nor the Gates 500/230 kV power transformer are overloaded after the DLO contingency. Of course, other lines or substation equipment might still determine the Path15 power flow limit.

Pre-contingency Loading

The rating (maximum pre-contingency loading) of Path15 is calculated as follows:

1. The CAT-1 monitors report the Gates-Panoche (GP) line's effective conductor temperature and weather conditions. Since one of the monitor locations is near the Gates substation, we use that air temperature for the transformer rating calculations. Electrical loads are available for all components as is the list of loads that may be shed if the DLO occurs ("remedial actions or RAS"), both those that are ready for automatic load shedding ("armed RAS") and all those that could be made available for automatic load shedding ("available RAS"). Transformer oil and winding temperatures may also be available in the future.

2. The post-contingency electrical loads on the GP line and on the Gates power transformer (GPT) are calculated through the use of "effectiveness factors" relating the pre-contingency loads on the 500 kV lines and the other monitored components to the post-contingency loads. "Effectiveness factors" are decimal fractions (derived by studying numerous load flow solutions) that equal the fraction of load shed at a particular location that reduces the load on Path15.

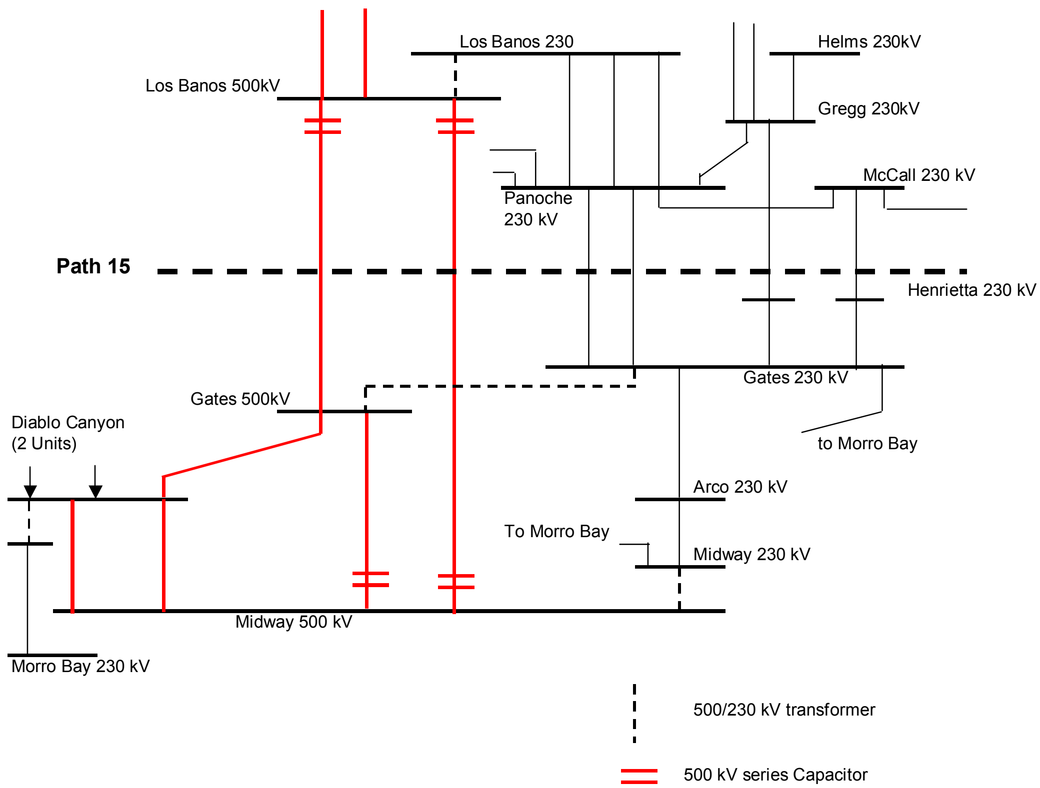


Figure 3-1
Circuit Diagram for "Path15" showing the component lines and the power transformer at Gates.

3. The calculated post-contingency loads are reduced according to the list of nearly instantaneous remedial actions (load reductions and generation reductions) and the ramp load reduction undertaken manually at Diablo Canyon. The post-contingency loads for the GP line and the Gates PT are calculated as shown in Figure 3-2.

4. The temperature of the GP line and the oil/winding temperatures and insulation aging of the Gates PT are calculated.

5. The loss-of-life and the possibility of gas bubble formation in the GPT windings are evaluated.

6. If the GP line temperature is less than 100°C, the GPT winding hot spot does not exceed 180°C, the %loss-of-life (insulation) is less than 1%, and gas bubbles are not predicted to form, the present pre-contingency Path15 load is incrementally increased and the calculation repeated. If any of the thermal limits are exceeded then the path load is incrementally decreased and the calculation repeated until all thermal limits are met. Additional work will be required to incorporate other system limiting conditions such as voltage and stability limits.

Post-Contingency Loading

The Path 15 rating software calculates Path 15 ratings limited by the loading of the Gates 530/230 kV transformer after the simultaneous loss of the two 500 kV lines on Path 15 (the DLO contingency). This thermal rating may change in response to one or more of the following events:

1. Change in thermal state of the transformer as evaluated by the PTLOAD/DTCR module.

2. Change in telemetered flows on the Gates to Los Banos 500 kV line, the Midway to Los Banos 500 kV line, or the Gates 500/230 kV transformer.

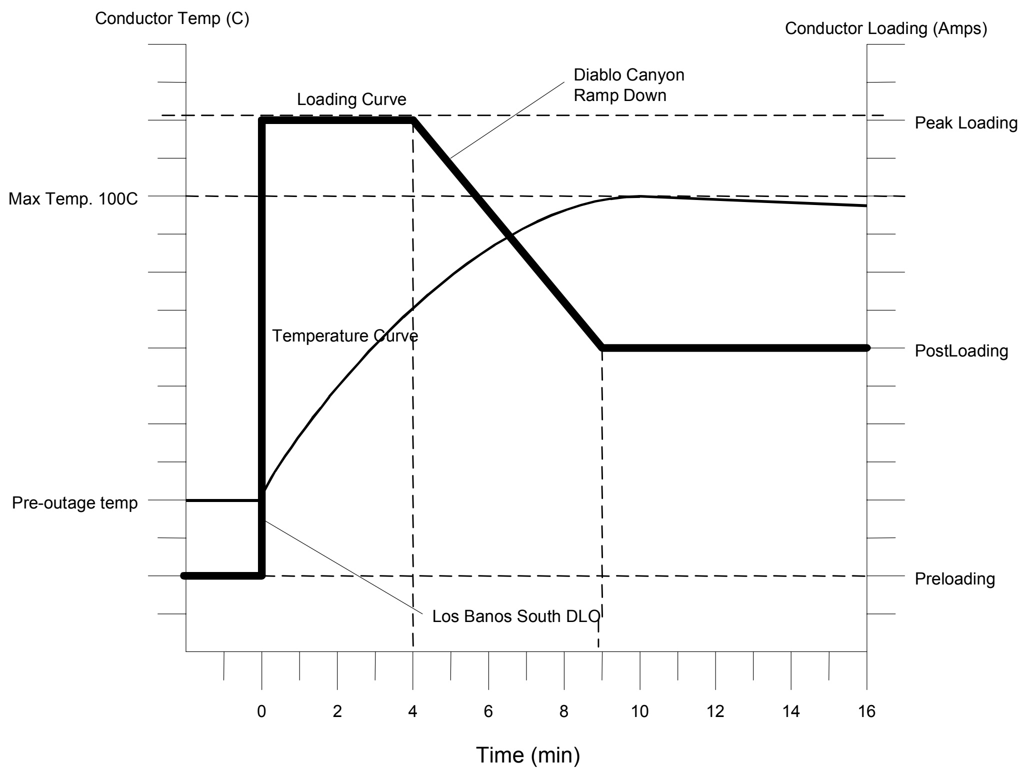


Figure 3-2
Post-contingency electrical load for Gates-Panoche 230 kV line and the Gates 500/230 kV autotransformers with the temperature response of the 230kV line.

3. Change in Remedial Action Scheme (RAS) arming or significant change in the amount of power available to be tripped for each RAS action. Ratings are calculated every 30 seconds based on data received from the RAS controller.

4. Change in the status of the remedial action available by run-back at Diablo Canyon.

5. Significant changes in the system configuration (i.e. various equipment outages) require the use of different sets of system model constants (distribution factors). These are changes that cause a significant change in the distribution of power among the Gates transformer and the 230 kV lines feeding the Gates 230 kV substation from the south. The software database incorporates 10 such sets of distribution factors. The system configuration is submitted to the Path 15 rating software from the RAS controller. The software uses the corresponding set of distribution factors.

Whenever the Gates 500/230 kV transformer limits the Path 15 rating, this Path15 power flow limitation is calculated and made available to the operator for two different conditions:

1. Assuming RAS action as currently “armed” (“armed” loads are those chosen randomly to be shed automatically from the list of all such loads)

2. Assuming that all available RAS actions are armed (i.e. all possible load reduction is taken).

4

PATH15 DYNAMIC RATING WITH GATES POWER TRANSFORMER

The calculation process is similar to the one applied to determine the Path 15 rating as limited by the loading of the Gates-Panoche (GP) 230 kV line after the Double Line Outage (DLO) contingency . The determination of the Path 15 limitation caused by the transformer loading differ from the limitation caused by the loading of the GP lines in the following respects:

1. Determination of the critical thermal parameters of the transformer requires a different calculation procedure. Present thermal conditions are updated continuously along with prediction of thermal conditions immediately after the DLO contingency and during the critical time period after the contingency when the transformer is operating at elevated temperatures.

2. The critical line maintenance outages (system configuration changes) that have a significant impact on the thermal limits are different.

3. The distribution factors used to calculate the loading of the transformer immediately after the contingency and the reduction in loading caused by RAS action and manual remedial action including the run-back of the Diablo Canyon generators are numerically different. However, the procedure for calculating these parameters is the same.

The most limiting of the thermal loading conditions on the Gates-Panoche 230 kV line or the Gates 500/230 kV transformer predicted for the DLO contingency determines the Path 15 rating unless there are other more limiting conditions such as may be caused by voltage criteria or reactive power criteria.

Post-contingency Loading of the Gates Transformer

Determination of the post contingency loading on the Gates 500/230 kV transformer includes the following items:

1. Calculation of transformer loading immediately after the DLO contingency

2. Calculation of the reduction in transformer loading obtained by the application of automatic RAS actions within one second of the DLO contingency

3. Calculation of the gradual reduction in post contingency loading of the transformer caused by the gradual run-back of the Diablo Canyon generation

The post DLO MW flow (**P'_{Gtx}**) on the Gates 500/230 kV transformer is calculated as follows:

$$\mathbf{P'_{Gtx} = P_{Gtx} + k_A * P_A + k_B * P_B} \qquad (1)$$

where:

P_A = pre-contingency MW flow on the Gates-Los Banos 500 kV line

P_B = pre-contingency MW flow on the Midway to Los Banos 500 kV line

P_{Gtx} = pre-contingency MW flow on the Gates 500/ 230 kV transformer.

k_A and **k_B** are constants (line outage distribution factors), valid for a particular pre-contingency system configuration. These k-values are numerically different from the k-values calculated for the Gates-Panoche 230 kV line.

The **k**-values vary only with changes in system impedances and system structure. They do not change (appreciably) with generation dispatch or load. Events that would result in a change in k-values would include the outage of a line in the neighborhood of Path 15 that would change the flow distribution between the transformer and the 230 kV lines feeding the Gates 230 kV bus from the south.

Using Equation 1, the flow on the Gates 500/230 kV transformer immediately after the DLO contingency is readily calculated from present pre-contingency MW values available in the SCADA system. Similarly, post-contingency flow values can be calculated for a future time period based on flow predictions obtainable from a load flow solution of forecast future conditions.

Pre-contingency Loading of Gates Power T

As a part of the Path 15 thermal rating calculation, it is necessary to calculate the change in post-contingency flow on the Gates 500/230 kV transformer for different transfer levels. This requires determination of the pre-contingency flows for changes in transfer levels for insertion in Equation 1.

Changes in **P_{Gtx}**, **P_A** and **P_B** with changes in the flow on Path 15 is related to the transfer (T) of power from south of Path 15 to north of Path 15 by the following equations:

The total flow across Path 15, $\mathbf{PP_{15} = k_{IF} * T}$ (2)

$\mathbf{P_{Gtx} = PDFG_{tx} * T = PDFG_{tx}/k_{IF}}$ * P P15

$\mathbf{P_A = PDF_A * T = PDF_A / k_{IF} * P\ P15}$

$\mathbf{P_B = PDF_B * T = PDF_B / k_{IF} * P\ P15}$

where:

PDF is Power Distribution Factor expressing the ratio of a change in circuit flow to a change in transfer.

$\mathbf{k}_{IF}$ is the PDF for the Path 15 "Inter Face" relating changes in Path 15 flow to changes in the transfer.

The distribution of the total transfer flow amongst circuits in the system is dependent on the transfer definition; that is from which buses and in what proportion are power injected in the sending system (south of Path 15) and absorbed in the receiving system (north of Path 15) when the south to north transfer is increased? In general, the PDF factors may be quite sensitive to these dispatch assumptions. However, in this case the structure of the system is such that the variation in PDF values with the selection of injection and absorption buses is quite small. Referring PDF values to the total flow across Path 15 rather than the transfer (T) further reduces this variation. This is obtained by dividing the original PDF values by kIF as shown in the Equation 2. Using these modified PDF factors also focuses calculations on the Path 15 MW flow (which can be measured directly) rather than on the south to north transfer which is not available as a measured quantity.

Significant Maintenance Outages

The distribution factors defined above are impacted by changes in system configuration which may occur when critical lines, transformers, series capacitors, or other station or line equipment are taken out on maintenance. Transfer limit analysis indicated that the parameters would be significantly impacted by maintenance outages of the 230 kV lines that feed the Gates 230 kV bus from the south. These lines are effectively in parallel with the Gates 500/230 kV transformer as seen from the Gates and Midway 500 kV buses:

- Gates-Arco 230 kV line or the Arco-Midway 230 kV line. The distribution factors were nearly identical for the two cases.
- Gates-Morro Bay 230 kV line
- Gates-Templeton-230 kV line or the Templeton-Morro Bay 230 kV line. The distribution factors were nearly identical for the two cases.
- Series Capacitors.
- 500 kV lines.

System Distribution Factors for Post-Contingency Loading

Table 4-1 lists distribution factors for the "all lines in" case and for the three line maintenance categories listed above. Calculations were performed using a "unit commitment" program. The following are the load flow cases and assumptions:

- Winter 2001 load flow case obtained from PG&E in April 2001.

- Linear system model assumptions.

- Transfer assumptions: Sending area included all generators above 100 MW in Southern California Edison. Receiving area included all generators above 100 MW in Oregon and Washington. The generators in the sending area were assumed to increase their output in proportion to their actual output in the load flow case. Similarly, the receiving end generators were assumed to decrease their output in proportion to their actual output in the load flow case. Reasonable variations in the sending and receiving area assumptions are not expected to have a significant impact on the results in this case.

Table 4-1 supports the following observations:

1. With all lines in service, the flow on the Gates 500/230 kV transformer increases by 7.8 MW for each 100 MW increase in Path15 power flow. The impact is 24% greater when the Midway-Arco-Gates 230 kV path is interrupted by a maintenance outage of either one of the 230 kV lines on this path.

2. The line outage distribution factors increases modestly (5 to 10%) for line outages on the Midway-Arco-Gates 230 kV path.

3. Maintenance outage of the Morro Bay-Gates 230 kV line or either one of the two lines on the Morro Bay-Templeton-Gates 230 kV path has significantly less impact than a maintenance outage on the Midway-Arco-Gates 230 kV path. There is essentially no difference between maintenance outages of lines on the two paths between Morro Bay and Gates.

Table 4-1
Distribution factors needed to calculate post-contingency flow on Gates 500/230 kV transformer for DLO outage at various transfer levels.

Base Case or Maintenance Case	PDF for Path15 kIF	PDF values normalized to P15 flow			Line Outage distribution factors for Gates 500/230 kV transformer	
		Gates-Los Banos 500 kV line PDF_A/kIF	Gates-Los Banos 500 kV line PDF_B/kIF	Gates 500/230 kV transformer PDF_{Gtx}/kIF	Gates-Los Banos 500 kV line k_A	Midway-Los Banos 500 kV line k_B
Base System Condition: All lines in service prior to DLO outage (no maintenance outages	0.774	0.438	0.427	0.078	0.610	0.523
Gates-Arco 230 kV line out of service (Arco-Midway outage should have substantially the same values)	0.773	0.438	0.433	0.097	0.644	0.578
Gates-Morro Bay 230 kV line out of service	0.774	0.438	0.429	0.083	0.619	0.538
Gates-Templeton 230 kV line out of service (Templeton-Morro Bay outage should have substantially the same values)	0.774	0.438	0.429	0.083	0.619	0.537

5

IMPACT OF RAS ACTIONS ON GATES PT LOADING

Generally the RAS system is designed to trip load (including pumps) north of Path 15 and generation in the Midway area, south of Path 15 when the DLO contingency occurs. The effectiveness of each of these actions; that is, the loading relief of the Gates 500/230 kV transformer that results from each action, is a function of:

- MW of load or generation tripped
- the response of the system to each trip

The RAS controller (a computer application) keeps track of the MW that will be tripped by each action. The set of actions that will be taken in a particular situation is in fact pre-computed by the RAS controller based on telemetered MW values of each trip that can be armed. Every 30 seconds the RAS controller arms a set of RAS actions that by its calculations will be sufficient to bring the post-contingency loading on the critical circuits down to an acceptable level given the present flow on Path 15. The critical circuits are the two Gates-Panoche 230 kV lines and the Gates 500/230 kV transformer. In either case, the effectiveness of each particular RAS action (line loading relief/MW tripped) is a complex function of system conditions and system control characteristics.

Tripping a breaker that causes a sudden change in the power injection at a particular bus effects a RAS action. The effectiveness of a specific RAS action is defined by an effectiveness factor (EF) as follows:

> **EF = MW reduction in flow on the Gates 500/230 kV transformer divided by the MW tripped by RAS action**

In order to compute EF, it is necessary to make an assumption as to how the tripped load or generation is compensated for in order to maintain the power balance in the system. EFs calculated here are based on the commonly used “inertial redispatch” assumption.

The “inertial redispatch” assumption assumes that immediately after RAS action that trips a load or a generator, each generator in service in the entire WSCC will vary its power output in proportion to its size until the power change caused by the trip is fully compensated for . Although this assumption is supported by generation control design concepts, the actual initial system response is subject to considerable uncertainty. Note that the results obtained will vary to some extent with the geographic distribution of generation on line across the WECC system.

As time progresses after the DLO occurrence, slower acting controls may gradually modify the initial system response. Automatic generation control systems, which remain enabled after the

DLO, are restorative and may tend to counteract the RAS action. The effectiveness factors calculated in this project assume that these slower control actions are not significant.

The automatic RAS action consists of tripped generation south of Path 15 in the neighborhood of Midway as well as tripped pumps and loads north of Path 15. Every 30 second, the RAS controller transmits armed and available RAS actions. Rather than providing information on each individual load or generator trip action, the RAS controller provides aggregate information on several groups of loads and generators. The individual loads or generators in a particular group are assumed to have the same effectiveness factors. The pumping facilities are represented as distinct and separate RAS actions. Table 5-1 summarizes the three pumping facilities, five load groups, and five generation groups considered in the present RAS system

Table 5-1
Summary of RAS actions

Group	Associated stations	Proxy bus in load flow representation
Delta pumping facility		38760 DELTA 1 115 kV
Dos Amigos pumping facility		38750 DOS AMG1 115 kV
San Luis pumping facility		38730 SANLUIS1 115 kV
Load Group 1	El Cerrito, Newark, Vaca Dixon, Monta Vista	32766 EL CRRTO 115 kV
Load Group 2	Lakewood, Pittsburg, Martin	32950 PITTSBURG 115 kV
Load Group 3	Gold Hill, San Mateo	32254 PLCRVLBC2 115 kV
Load Group 4	Fulton, Ignacio	32568 IGNACIO 115 kV
Load Group 5	Green Valley, Moss Landing, Salinas, Stagg	35907 PAUL SWT 115 kV
Generation Group 1	Kern, Kern Oil, Midsun, Midway, Sunrise	30970 MIDWAY 230 kV
Generation Group 2	Elk Hills generating station	30970 MIDWAY 230 kV
Generation Group 3	La Paloma units 1 and 2	30970 MIDWAY 230 kV
Generation Group 4	Midway (Sunset generation facility)	30970 MIDWAY 230 kV
Generation Group 5	La Paloma units 3 and 4	30970 MIDWAY 230 kV

While each of the pumping facilities takes power from one specific substation, each load group represents loads at a number of different substations. Thus the effectiveness in reducing the loading of the Gates 500/230 kV transformer (per MW of load tripped) is not necessarily the same for each individual load bus in a specific load group. However, the effectiveness factors for each of the individual loads tripped in a group are close enough to be considered “essentially identical". This allows the representation of individual load reductions by means of a "**proxy bus**" for the group. A proxy bus is chosen as:

- Electrically central in the cluster of buses comprising the load group
- Has an effectiveness factor that is representative of the mean of all effectiveness factors for the load buses in the group.

The proxy bus for each group of associated stations is listed in Table 5-1. The proxy bus for a group was selected based on two criteria:For example, the effectiveness factor for El Cerrito in Load Group 1 is about 2% lower than for Newark and about 1.5 % higher than for Vaca Dixon. The spread in the effectiveness factors is generally so small that the selection of the proxy bus is not a critical issue.

The effectiveness factors for each of the generators tripped in all five generation groups are essentially the same and can be represented by the effectiveness factor calculated for the Midway 230 kV bus.

Calculated effectiveness factors for the "all lines in" pre-contingency condition and the three maintenance outage categories are summarized in Table 5-2. Table 5-3 shows the same data in per unit of the "all lines in" case.

Table 5-2 shows the effectiveness factor as the fractional MW change in transformer loading for a 1 MW reduction in power injection at the proxy buses representing the various RAS actions. Thus, the tripping of load including pumping load north of Path 15 has a negative effectiveness factor and the tripping of a generator south of Path 15 has a positive factor. In either case, the result of the tripping action is a reduction in the loading of the Gates transformer in the 500 to 230 kV direction. The impacts are additive. Further, it is of interest to note that if the generation tripped matches the load (including pumping load) tripped, any approximation introduced by the inertial redispatch assumption will be eliminated for that system condition.

Table 5-2
RAS effectiveness factors for reducing loading on Gates 500/230 kV transformer during DLO contingency and additional maintenance outages. Inertial redispatch with some blocked generators assumed.

RAS Group	All lines in	Templeton to Gates 230 kV	Morro Bay to Gates 230 kV	Arco to Gates 230 kV
Delta pumping facility	-0.215	-0.222	-0.222	-0.238
Dos Amigos pumping facility	-0.258	-0.266	-0.267	-0.285
San Luis pumping facility	-0.244	-0.252	-0.253	-0.270
Load Group 1	-0.214	-0.221	-0.221	-0.237
Load Group 2	-0.214	-0.221	-0.222	-0.237
Load Group 3	-0.209	-0.216	-0.217	-0.232
Load Group 4	-0.212	-0.219	-0.220	-0.235
Load Group 5	-0.224	-0.231	-0.231	-0.248
Generation groups 1-5	0.200	0.215	0.215	0.263

Table 5-3
Impact of maintenance outages on RAS effectiveness factors derived from Table 5-2. Impacts greater than 5% are in bold type.

RAS Group	All lines in	Templeton to Gates 230 kV	Morro Bay to Gates 230 kV	Arco to Gates 230 kV
Delta pumping facility	1.000	1.034	1.035	**1.107**
Dos Amigos pumping facility	1.000	1.033	1.034	**1.107**
San Luis pumping facility	1.000	1.033	1.034	**1.106**
Load Group 1	1.000	1.034	1.035	**1.107**
Load Group 2	1.000	1.034	1.036	**1.107**
Load Group 3	1.000	1.034	1.035	**1.107**
Load Group 4	1.000	1.034	1.035	**1.107**
Load Group 5	1.000	1.034	1.035	**1.107**
Generation groups 1-5	1.000	**1.076**	**1.078**	**1.317**

A maintenance outage that have no significant direct impact on the flow on the Gates 500/230 kV transformer may still have an impact on the RAS effectiveness factors. Two such maintenance outages were identified as shown in Table 5-4.

Table 5-4
Supplementary RAS effectiveness factors for maintenance outages that do not have a significant direct impact on the flow on the Gates 500/230 kV transformer. Impact differences greater than 5% relative to the 'all lines in' case are in bold type.

RAS Group	All lines in	Dos Amigos to Panoche 230 kV		Dos Amigos to Los Banos 230 kV	
	EF	EF	PU	EF	PU
Delta pumping facility	-0.215	-0.212	0.987	-0.212	0.987
Dos Amigos pumping facility	-0.258	-0.239	**0.925**	-0.288	**1.118**
San Luis pumping facility	-0.244	-0.239	0.976	-0.239	0.976
Load Group 1	-0.214	-0.211	0.987	-0.211	0.987
Load Group 2	-0.214	-0.211	0.987	-0.211	0.987
Load Group 3	-0.209	-0.207	0.989	-0.207	0.989
Load Group 4	-0.212	-0.209	0.987	-0.209	0.987
Load Group 5	-0.224	-0.222	0.992	-0.222	0.992
Generation groups 1-5	0.200	0.196	0.981	0.196	0.981

From Table 5-4 one might consider the impact on the effectiveness of the Dos Amigos pumping facility to be significant and thus justify including the maintenance of the Dos Amigos to Panoche and Dos Amigos to Los Banos lines in the determination of the Path 15 rating when limited by the Gates 500/230 kV transformer.

Effectiveness of Diablo Canyon Run-back

The effectiveness factor for Diablo Canyon, calculated the same way as the effectiveness factors for the RAS actions, is 0.332. System operators will attempt to match the run-back of Diablo Canyon with a corresponding ramping up of generation in the Bay area. Using the Pittsburg 115 kV bus as a proxy bus for the Bay area, the effectiveness factor for the run-back at Diablo

Canyon, matched MW for MW with a ramping up of generation in the Bay area, is 0.332 + 0.2140 = 0.536. That is, a 1000 MW run-back of Diablo Canyon accompanied by a 1000 MW ramping of generation in the Bay area would result in a 536 MW reduction in loading on the Gates 500/230 kV transformer. Under this assumption, approximations introduced by the inertial dispatch assumption would be eliminated for this condition.

6
EXAMPLE CALCULATION

Using the method outlined above, the Gates transformer loading can be calculated for an example case. This example assumes all equipment is in service (i.e. no maintenance condition).

Application of Effectiveness Factors

P_A = pre-contingency MW flow on Gates-Los Banos 500 kV line = -769.2 MW

P_B = pre-contingency MW flow on Midway to Los Banos 500 kV line = -798.6 MW

PG_{tx} = pre-contingency MW flow on Gates 500/ 230 kV transformer bank = 553.5 MW

The post DLO MW flow on the Gates 500/230 kV transformer is calculated as follows:

$P'G_{tx} = PG_{tx} + k_A * P_A + k_B * P_B = 553.5 + -0.61 * -769.2 + -0.523 * -798.6 = 1440.4$ MW

Next, the effect of the RAS in reducing the post DLO MW flow must be considered. For this example, we consider the "armed" RAS with the following values for each RAS group:

Table 6-1
Armed and available RAS

		MW (+/GEN, -/LD)	
Label	**Location**	**Armed**	**Available**
HELMS 1 18.0	4	0	0
SANLUIS113.8	1	-152	-152
DOS AMG113.2	2	-67	-67
DELTA 1 13.2	3	-158	-158
Load Group 1	5	0	0
Load Group 2	6	0	0
Load Group 3	7	0	0
Load Group 4	8	0	0
Load Group 5	9	0	0
Gen Group 1	10	0	486
Gen Group 2	11	0	0
Gen Group 3	12	0	0
Gen Group 4	13	0	0
Gen Group 5	14	0	0

Using the effectiveness factors presented above, the impact of each of the above “armed” RAS actions can be calculated:

San Luis = -152 * -0.244 = 37.2 MW

Dos Amigos = -67 * -0.258 = 17.3 MW

Delta = -158 * -0.215 = 44.0 MW

The MW armed for the remaining RAS groups is 0 MW, therefore the impact of these RAS groups will be 0MW. Summing these values, the total reduction in the post DLO MW flow on the Gates transformer bank is then 88.3 MW. Subtracting this from the post DLO MW flow calculated above gives a net post DLO MW flow (with RAS) of 1352.1 MW.

Four minutes after the start of the DLO, the generation at Diablo Canyon is ramped down at a rate of 200 MW/minute for 5 minutes. The total effect of this ramp down is a reduction in the post DLO DLR MW flow from 1352.1 MW at 4 minutes to 1020.1 MW at 9 minutes.

Input Data for the DTCR Transformer Thermal Model

The DTCR/PTLOAD thermal models are based directly on IEEE Standard C57.91-1995, “Guide for Loading Mineral-Oil-Immersed Transformers”. The thermal parameters required by the software are familiar to most transformer engineers. Nonetheless, as is always the case, certain information was not available and assumptions, estimates and calculations of the various parameters had to be made. These assumptions, estimates and calculations are described in this report. They were made using the available information to the extent possible and filling in the gaps using transformer design principles.

The IEEE Standard C57.91-1995 allows for two thermal models: the conventional “top oil” and the newer, more complex, “bottom oil” model. The “top oil” model is most commonly used by utility transformer engineers and has been the recommended calculation method since the original loading guide in 1945. In recent years, attempts have been made to correct some inaccuracies in the “top oil” model, mainly the behavior in short durations, by means of the “bottom oil” model that includes a winding duct oil rise that increases rapidly with the winding time constant. Recent thermal testing on model coils and using fiber optic temperature sensors have indicated that this is an important consideration for short duration or rapidly changing overloads. Given the very short loading duration resulting from a Double Line Outage in Path15 (less than 15 minutes) the bottom oil model is used.

The following table summarizes the thermal model parameters to be used to model the Gates transformers with the bottom oil model.

Table 6-2
Bottom oil model thermal parameters

	STAGE 1	STAGE 2	STAGE 3
Type of cooling	*OA*	*FA*	*NDFOA*
Nameplate rating	*200*	*267*	*374*
Rated ambient temperature	*40.0*	*40.0*	*30.0*
Top fluid rise over ambient	*43.0*	**40.0**	*28.4*
Bottom fluid rise over ambient	**30.0**	**30.0**	**22.0**
Hot spot rise over ambient	**52.3**	**55.0**	**70.5**
Hot spot location (fraction of winding)	*1.0*	*1.0*	*1.0*
Rated avg winding rise over ambient	*55.0*	*55.0*	*65.0*
Tested avg winding rise over ambient	*42.3*	**45.0**	*55.5*
Winding thermal time constant (min)	**18.05**	**10.78**	**6.77**
Exponent for duct fluid rise over bottom oil	0.5	0.5	0.5
Exponent for avg fluid rise over bottom oil	0.8	0.9	0.9
Exponent for top to bottom fluid rise diff	0.5	0.5	1.0
Eddy loss per winding loss at hot spot	0.2	0.2	0.2

Items in italics were obtained directly from the test report. Items in bold type are estimated. Items in normal type are defaults (from IEEE C57.91-1995) that are usually not changed unless there is detailed heat run data that suggests that these values are incorrect.

The manufacturer's test report includes heat run data for the OA cooling mode at 200MVA (55°C average winding rise) and the FOA cooling mode at 374MVA (65°C avg. winding rise). Heat run data for the FA cooling mode was estimated from the heat run data for the other two cooling modes.

Bottom Oil Temperatures

The bottom oil model is generally accepted to be more accurate for short (< 1 or 2 hrs) duration overloads, and therefore would be desirable in this case. The bottom oil model, however, requires bottom oil temperatures at rated load. This information is not available from the test report. Initial values for bottom oil rise at rated load were estimated by assuming a typical top-to-bottom oil gradient for a given cooling mode type.

These values may be refined by either contacting the manufacturer (may be difficult and will likely incur a fee) or by taking a series of temperature measurements using a magnetic thermocouple places on the underside of the radiator inlet. Top oil temperature, ambient air temperature, pump/fan state and load would also have to be measured/recorded.

Winding Thermal Time Constant

Since the overloads that we are considering in this application are of short duration (< 15min), the winding time constant becomes a critical parameter. The differences between using a time constant of 5 minutes versus 15 minutes are substantial. Therefore, an effort has been made to calculate the winding time constant with greater accuracy than assuming a value of 5 minutes. The following is an outline of the calculation of the winding time constant (Γ_w) for each of the three cooling modes:

Weight of windings estimated at 33,600 lbs (Untanking weight is 245,000 lbs).

Winding time constant = $\Gamma_{w=}$ ΔTu * C * Mw / LL

Where,

ΔTu is the average winding rise

C = 3.0 when Copper only is involved (a conservative approximation)

Mw is the mass of the windings = 33,600 as described above

LL is the load loss

For Stage 1 (200MVA):

Γ_w = 42.3 * 3.0 * 33,600 / 236,200 = 18.05 min.

For Stage 2 (267MVA):

Γ_w = 45.0 * 3.0 * 33,600 / 420,962 = 10.78 min.

For Stage 3 (374MVA):

Γ_w = 55.5 * 3.0 * 33,600 / 825,968 = 6.77 min.

Losses

Losses are fairly straightforward and were taken directly from the test report. There is one point to note here, however. The bottom oil model, as published in Annex G of C57-91-1995, requires the losses to be broken down into winding I^2R losses, winding eddy losses, stray losses and core losses. The core losses are simply taken as the no-load losses. The winding I^2R losses are calculated by multiplying the square of the rated winding load current by the winding DC resistance. The winding eddy losses and the stray losses comprise the difference between the winding I^2R losses and the load losses listed on the test report. As is recommended in C57.91-

1995, the winding eddy losses are assumed to be 0 and the stray loss is then the load losses minus the winding I^2R loss. The resulting assignment of losses is as follows:

Winding I2R Loss	170524.8
Winding Eddy Loss	0.0
Stray Loss	65675.2
Core Loss	108200.0

Cooling Stage Switching

From the test report, it appears as though the unit is equipped with AWR-102 Winding Temperature Indicators. These winding temperature indicators are equipped with three snap action switches located inside the sealed indicator unit. These switches are provided to be used for cooling stage switching and alarm operation. The first two switches are intended to control the cooling equipment for the FA and FOA stages. The third switch is used for alarm operation.

The switches are set to operate at rising temperatures with the following factory presets:

Switch No. 1 (OA to FA) 80°C

Switch No. 2 (FA to FOA) 85°C

Switch No. 3 (Alarm) 120°C

On falling temperatures, the switches operate between 5°C and 10°C below these settings.

For now, it is assumed that the AWR-102 WTI's are used to control the cooling equipment. Also, it is assumed that the switch thresholds are still set at the factory presets. If this is not true, then the inputs to PTLOAD will need to be changed.

In addition, the winding temperature indicators have a degree of error inherent in their design. It is assumed that the error is small enough to be neglected. PTLOAD, and therefore TML4, does not include the capability of modeling the WTI separately.

Based on the above, the cooling stage switching is set to operate on the hot spot temperature with the following thresholds:

Change from 1st to 2nd at a hot spot temp. $\geq$ 80°C

Change from 2nd to 3rd at a hot spot temp.$\geq$ 85°C

Change from 2nd to 1st at a hot spot temp.$\leq$ 73°C

Change from 3rd to 2nd at a hot spot temp.$\leq$ 78C

Bubble Evolution

This unit is equipped with GE's Atmoseal conservator, which is simply a GE trade name for a membrane conservator.

The parameters required for the bubble evolution model were taken from the Dissolved Gas Analysis (DGA) and oil quality data provided. The bubble model in PTLOAD requires several parameters, mainly moisture content of the paper at the hot spot location and the concentration of N2, CO, CO2, and O2. The gas concentrations were taken directly from the DGA reports, using the most conservative set of data. Slight variations in gas concentration have little or no effect on the determination of bubble evolution.

The most difficult to obtain parameter, and the most crucial parameter to the determination of the onset of bubble evolution is the moisture content of the paper at the hot spot location. This value may be calculated from the moisture content of the bulk cellulose.

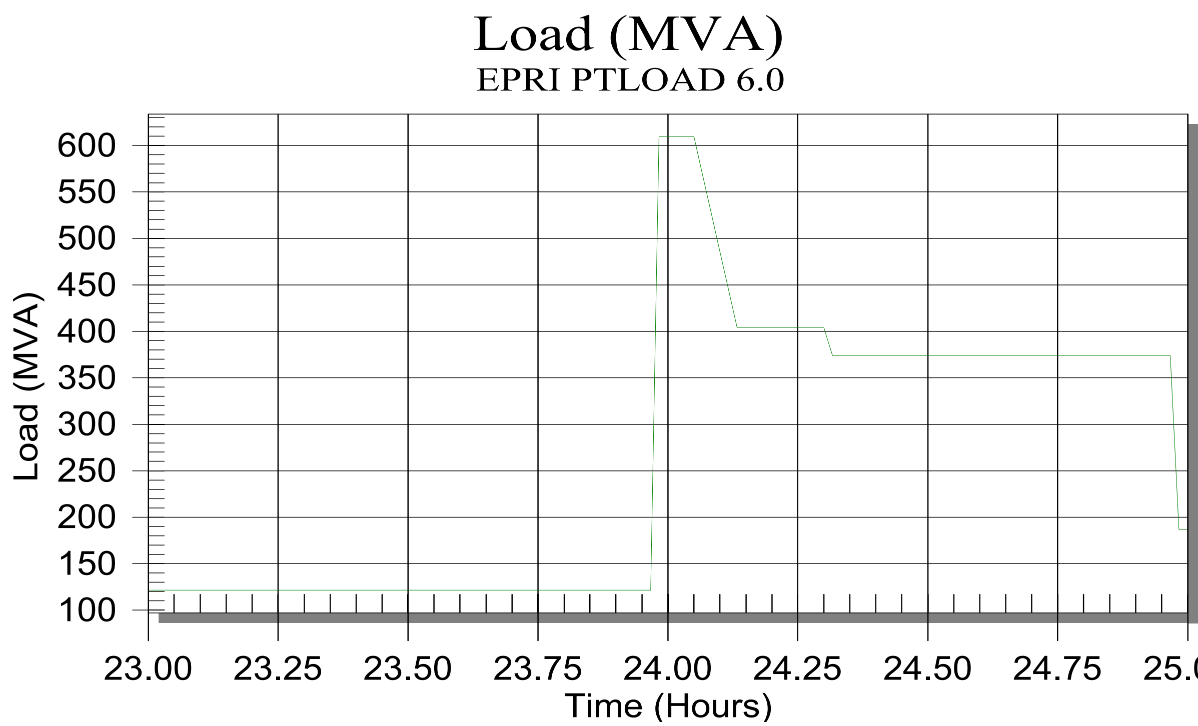
The moisture content of the bulk cellulose is still difficult to determine without a complete set of moisture content in oil data. If the moisture content in oil was measured (along with the oil temperatures) a fairly good approximation of the moisture content of the bulk cellulose could be determined from the moisture oil-paper equilibrium curves. Not enough data was available to use this approach. Rather, a conservative 3% moisture content in the bulk cellulose was assumed. Based on this level of moisture in the bulk cellulose, the moisture content of the paper at the hot spot was calculated to be 1.47%.

Transformer Rating - Calculation Example

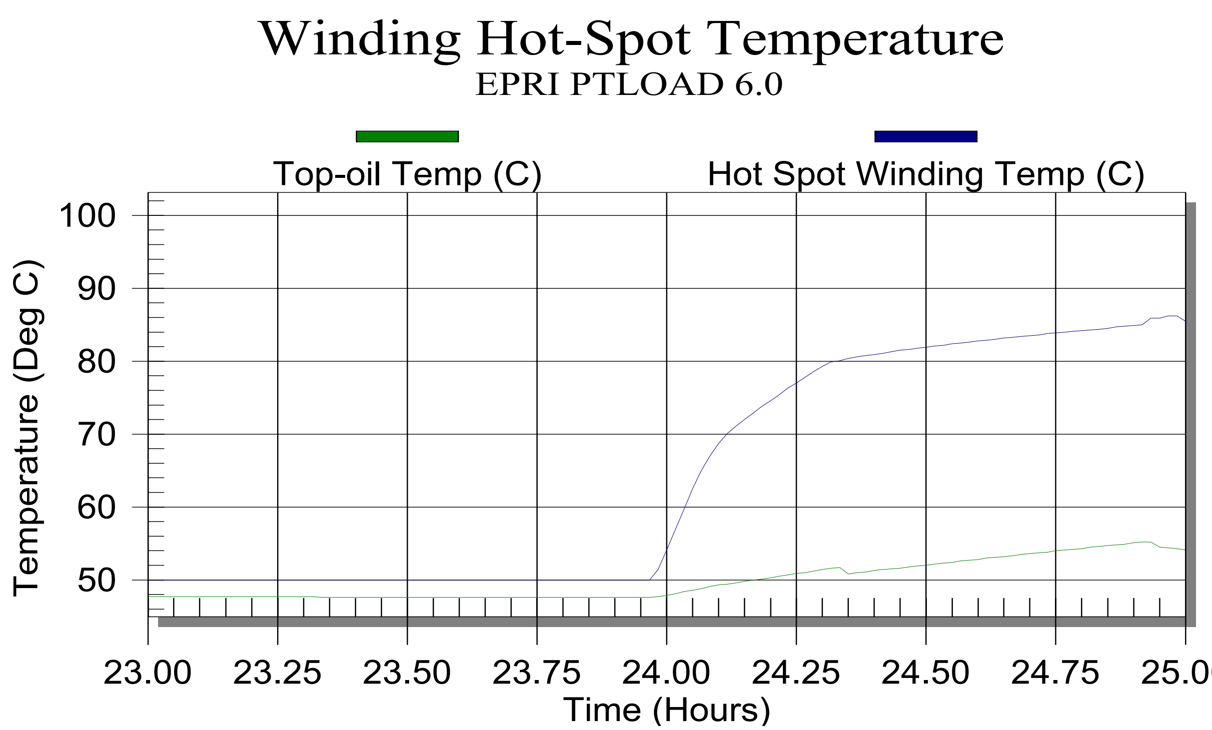
To demonstrate the results of the model, a calculation was performed using a constant 20C ambient temperature and a load shape as follows:

- Pre Contingency ($t < 0$) - 400 amps
- Post Contingency ($0 < t < 4$min) - 2000 amps (before Diablo ramp)
- Post Contingency and Diablo ramp (9min < t < 20min) - 1325 amps
- Also, the following estimates are made:
- 20 minutes after the outage: Transformer at 100% of 1120 MVA nameplate - 1230 amps
- 60 minutes after the outage: Transformer at 50% of 1120 MVA nameplate - 615 amps (may be higher depending on system conditions)

A plot of this load shape is shown below:



The results of this calculation are shown in the plot below as well as the output report following the plot:



PTLOAD Version 6.0
FILE NAME: Gates_bottomoil.run
TIME OF RUN: 6/17/2002 11:04:00 PM

CALCULATION PERFORMED: Temperature Profile Run, Plan Mode

A. Input Summary

Transformer Parameters	
Transformer:	K546561
Station:	Gates
Comments:	525/230kV 200/267/334//374MVA OA/FA/FOA
Winding voltage used for calculations:	230 kV, 1 phase
Insulation system:	65 Deg Rise
Insulation LOL param B:	15000
Insulation life (hrs):	180000
Model type:	Bottom oil model
Perform rating calculations:	No
Output step time (hrs):	0.01666667
Apply load multiplier:	No
Apply temp. offset:	No
Run from start of data:	Yes
Run to end of data:	Yes
Core weight (lbs):	245000
Tank weight (lbs):	158000
Oil volume (gal):	28300
Adj time constant:	Yes
Number of cooling stages:	3
Allow switching:	Yes
Cooling switching mode:	Cooling tracks hotspot
Switching temperatures (C):	.
stage 1 to 2:	80
stage 2 to 1:	73
stage 2 to 3:	85
stage 3 to 2:	78
Bottom-oil physical parameters	
Winding conductor type:	Cu
Cooling fluid type:	OIL
Specific heat of fluid (W-min/lb-C):	13.92
Fluid density (Lbs per cubic inch):	0.031621
1st const in visc. eq. (centipoise):	0.0013473
2nd const in visc. eq. (C):	2797.3
Weight of core and coils (lbs):	245000
Weight of tank and fittings (lbs):	158000
Volume of cooling fluid (gal):	28300
Spec. heat of tank steel (W-min/lb-C):	3.51
Winding temp factor (C):	234.5
Winding specific heat (W-min/lb-DegC):	2.91
Bottom-oil loss parameters	
KVA base for loss data:	200000
Temp base for loss data (C):	75

Winding I^2R loss (W):	170524.8
Winding eddy loss (W):	0
Stray losses (W):	65675.2
Core loss (W):	108200
Total loss (W):	344400
Is overexcitation assumed to occur:	No
Evaluate bubble evolution:	Yes
Oil pressure type:	MEMBRANE CONSERVATOR
Avg top oil temp (C):	35
Avg winding hotspot (C):	50
Moisture (%):	3
Hotspot moisture (%):	1.47
Gas pressure (mm Hg):	760
Carbon monoxide (ppm):	500
Carbon dioxide (ppm):	1500
Oxygen (ppm):	2600
Nitrogen (ppm):	40000
Height oil over hs (in):	72

Cooling Parameters			
Parameter name	Stage 1	Stage 2	Stage 3
Type of cooling	OA	FA	Non-directed flow FOA, FOW
Nameplate rating (MVA)	200.000	267.000	374.000
Rated ambient temp (C):	40.000	40.000	30.000
Top fluid rise over ambient (C):	43.000	40.000	28.400
Bottom fluid rise over amb. (C):	30.000	30.000	22.000
Hot spot rise over ambient (C):	52.300	55.000	70.500
Hot spot location (fraction):	1.000	1.000	1.000
Rated average winding rise (C):	55.000	55.000	65.000
Tested avg wind rise / amb. (C):	42.300	45.000	55.500
Winding time constant (min):	18.050	10.780	6.770
Exponent for duct fluid rise:	0.500	0.500	0.500
Exponent for fluid rise:	0.800	0.900	0.900
Top-bottom fluid rise diff exp.:	0.500	0.500	1.000
Eddy loss / winding loss at HS:	0.200	0.200	0.200

Load and Air Temperature Sources	
Load Source	
Source file:	Gates_load.txt
Lines to skip:	1
Date column:	1
Time column:	2
Data column:	3
Time format:	HH:MM:SS
Date format:	MM/DD/YY
Load units:	Per Unit Nameplate

Temperature Source	
Source file:	Gates_load.txt
Lines to skip:	1
Date column:	1
Time column:	2
Data column:	4
Time format:	HH:MM:SS
Date format:	MM/DD/YY
Temperature units:	DegC

B. Output Summary

```
Peak Load (MVA)            = 609.62
Peak Load (Amps)           = 2650.522
Peak Load (PU)             = 1.63
Max Hot Spot (Deg C)       = 100.5
Max Top Oil (Deg C)        = 59.76068
Max Hot Spot Oil (Deg C)   = 85.5
Max Top Duct Oil (Deg C)   = 85.5
Max Bottom Oil (Deg C)     = 52
Peak Age Accel Factor      = 0.3695896
Cumulative Loss of Life (Percent)  = 0.0001465529
Max Bubble Risk (mmHg)     = -9999   (a negative value means bubbles are not likely)

Given the temperature and load profile given, bubbles were not likely to form during
the time period evaluated. The maximum risk occurred -282509 hours into the evaluation.
```

PTLOAD transformer temperature and thermal rating calculations are based on the mathematical methods described in IEEE C57.91-1995 and IEC 354-1991-09.

Output Results

Date	Time	Ambient Temp (C)	Top-oil Temp (C)	Bottom-oil temp (C)	Hot Spot Winding Temp (C)	Duct top-oil temp (C)	Hot-spot oil temp (C)	Load (MVA)	Load (Amps)	Load (per unit)	Incr. Loss of Life (%)	Cumul. Loss of Life (%)	Age accel. factor	Cooling stage number	Excess bubble pressure (mmHg)
03/25/02	01:00:00	20.0	58.5	46.4	64.9	56.9	56.9	121.5500	528.5	0.325000	0.00002	0.00002	0.00535	1	0.0
03/25/02	02:00:00	20.0	57.1	45.3	59.9	53.8	53.8	121.5500	528.5	0.325000	0.00000	0.00002	0.00274	1	-9999.0
03/25/02	03:00:00	20.0	55.7	44.2	57.7	52.3	52.3	121.5500	528.5	0.325000	0.00000	0.00002	0.00205	1	-9999.0
03/25/02	04:00:00	20.0	54.5	43.3	56.4	51.2	51.2	121.5500	528.5	0.325000	0.00000	0.00002	0.00171	1	-9999.0
03/25/02	05:00:00	20.0	53.5	42.5	55.4	50.3	50.3	121.5500	528.5	0.325000	0.00000	0.00002	0.00149	1	-9999.0
03/25/02	06:00:00	20.0	52.6	41.8	54.6	49.5	49.5	121.5500	528.5	0.325000	0.00000	0.00002	0.00133	1	-9999.0
03/25/02	07:00:00	20.0	51.8	41.2	53.9	48.8	48.8	121.5500	528.5	0.325000	0.00000	0.00002	0.00120	1	-9999.0
03/25/02	08:00:00	20.0	51.2	40.7	53.3	48.3	48.3	121.5500	528.5	0.325000	0.00000	0.00002	0.00111	1	-9999.0
03/25/02	09:00:00	20.0	50.6	40.2	52.7	47.8	47.8	121.5500	528.5	0.325000	0.00001	0.00003	0.00103	1	-9999.0
03/25/02	10:00:00	20.0	50.1	39.9	52.3	47.4	47.4	121.5500	528.5	0.325000	0.00000	0.00003	0.00097	1	-9999.0
03/25/02	11:00:00	20.0	49.7	39.6	51.9	47.0	47.0	121.5500	528.5	0.325000	0.00000	0.00003	0.00092	1	-9999.0
03/25/02	12:00:00	20.0	49.4	39.3	51.6	46.7	46.7	121.5500	528.5	0.325000	0.00000	0.00003	0.00088	1	-9999.0
03/25/02	13:00:00	20.0	49.1	39.1	51.3	46.5	46.5	121.5500	528.5	0.325000	0.00000	0.00003	0.00084	1	-9999.0
03/25/02	14:00:00	20.0	48.8	38.9	51.1	46.3	46.3	121.5500	528.5	0.325000	0.00000	0.00003	0.00082	1	-9999.0

03/25/02	15:00:00	20.0	48.6	38.7	50.9	46.1	46.1	121.5500	528.5	0.325000	0.00000	0.00003	0.00079	1	-9999.0
03/25/02	16:00:00	20.0	48.4	38.5	50.7	45.9	45.9	121.5500	528.5	0.325000	0.00000	0.00003	0.00077	1	-9999.0
03/25/02	17:00:00	20.0	48.3	38.4	50.6	45.8	45.8	121.5500	528.5	0.325000	0.00000	0.00003	0.00076	1	-9999.0
03/25/02	18:00:00	20.0	48.1	38.3	50.4	45.6	45.6	121.5500	528.5	0.325000	0.00000	0.00003	0.00074	1	-9999.0
03/25/02	19:00:00	20.0	48.0	38.2	50.3	45.5	45.5	121.5500	528.5	0.325000	0.00000	0.00003	0.00073	1	-9999.0
03/25/02	20:00:00	20.0	47.9	38.1	50.2	45.5	45.5	121.5500	528.5	0.325000	0.00000	0.00003	0.00072	1	-9999.0
03/25/02	21:00:00	20.0	47.8	38.1	50.2	45.4	45.4	121.5500	528.5	0.325000	0.00000	0.00003	0.00071	1	-9999.0
03/25/02	22:00:00	20.0	47.7	38.0	50.1	45.3	45.3	121.5500	528.5	0.325000	0.00000	0.00003	0.00071	1	-9999.0
03/25/02	23:00:00	20.0	47.7	38.0	50.0	45.3	45.3	121.5500	528.5	0.325000	0.00000	0.00003	0.00070	1	-9999.0
03/26/02	00:00:00	20.0	47.7	38.0	51.4	45.2	45.2	609.6200	2650.5	1.630000	0.00000	0.00003	0.00073	1	-9999.0
03/26/02	01:00:00	20.0	54.3	46.4	86.2	74.1	74.1	187.0000	813.0	0.500000	0.00002	0.00005	0.07345	3	-9999.0
03/26/02	02:00:00	20.0	56.4	44.7	67.3	56.8	56.8	187.0000	813.0	0.500000	0.00001	0.00006	0.00738	1	-9999.0
03/26/02	03:00:00	20.0	56.9	45.2	65.7	56.5	56.5	187.0000	813.0	0.500000	0.00001	0.00007	0.00599	1	-9999.0
03/26/02	04:00:00	20.0	57.2	45.4	65.7	56.8	56.8	187.0000	813.0	0.500000	0.00000	0.00007	0.00600	1	-9999.0
03/26/02	05:00:00	20.0	57.5	45.7	65.9	57.0	57.0	187.0000	813.0	0.500000	0.00000	0.00007	0.00617	1	-9999.0
03/26/02	06:00:00	20.0	57.8	45.8	66.1	57.2	57.2	187.0000	813.0	0.500000	0.00001	0.00008	0.00634	1	-9999.0
03/26/02	07:00:00	20.0	58.0	46.0	66.3	57.4	57.4	187.0000	813.0	0.500000	0.00000	0.00008	0.00649	1	-9999.0
03/26/02	08:00:00	20.0	58.1	46.1	66.5	57.5	57.5	187.0000	813.0	0.500000	0.00000	0.00008	0.00662	1	-9999.0
03/26/02	09:00:00	20.0	58.3	46.3	66.6	57.6	57.6	187.0000	813.0	0.500000	0.00001	0.00009	0.00674	1	-9999.0
03/26/02	10:00:00	20.0	58.4	46.4	66.7	57.8	57.8	187.0000	813.0	0.500000	0.00000	0.00009	0.00684	1	-9999.0
03/26/02	11:00:00	20.0	58.5	46.4	66.8	57.8	57.8	187.0000	813.0	0.500000	0.00000	0.00009	0.00692	1	-9999.0
03/26/02	12:00:00	20.0	58.6	46.5	66.9	57.9	57.9	187.0000	813.0	0.500000	0.00001	0.00010	0.00699	1	-9999.0
03/26/02	13:00:00	20.0	58.7	46.6	67.0	58.0	58.0	187.0000	813.0	0.500000	0.00000	0.00010	0.00705	1	-9999.0
03/26/02	14:00:00	20.0	58.7	46.6	67.0	58.0	58.0	187.0000	813.0	0.500000	0.00001	0.00011	0.00711	1	-9999.0
03/26/02	15:00:00	20.0	58.8	46.7	67.1	58.1	58.1	187.0000	813.0	0.500000	0.00000	0.00011	0.00715	1	-9999.0
03/26/02	16:00:00	20.0	58.8	46.7	67.1	58.1	58.1	187.0000	813.0	0.500000	0.00000	0.00011	0.00719	1	-9999.0
03/26/02	17:00:00	20.0	58.9	46.7	67.1	58.2	58.2	187.0000	813.0	0.500000	0.00001	0.00012	0.00722	1	-9999.0
03/26/02	18:00:00	20.0	58.9	46.8	67.2	58.2	58.2	187.0000	813.0	0.500000	0.00000	0.00012	0.00725	1	-9999.0
03/26/02	19:00:00	20.0	58.9	46.8	67.2	58.2	58.2	187.0000	813.0	0.500000	0.00001	0.00013	0.00727	1	-9999.0
03/26/02	20:00:00	20.0	59.0	46.8	67.2	58.2	58.2	187.0000	813.0	0.500000	0.00000	0.00013	0.00729	1	-9999.0
03/26/02	21:00:00	20.0	59.0	46.8	67.2	58.3	58.3	187.0000	813.0	0.500000	0.00000	0.00013	0.00731	1	-9999.0
03/26/02	22:00:00	20.0	59.0	46.8	67.3	58.3	58.3	187.0000	813.0	0.500000	0.00001	0.00014	0.00733	1	-9999.0
03/26/02	23:00:00	20.0	59.0	46.8	67.3	58.3	58.3	187.0000	813.0	0.500000	0.00000	0.00014	0.00734	1	-9999.0
03/27/02	00:00:00	20.0	59.0	46.8	67.3	58.3	58.3	187.0000	813.0	0.500000	0.00001	0.00015	0.00735	1	-9999.0

7

DTCR POWER TRANSFORMER MODEL – SENSITIVITY STUDIES

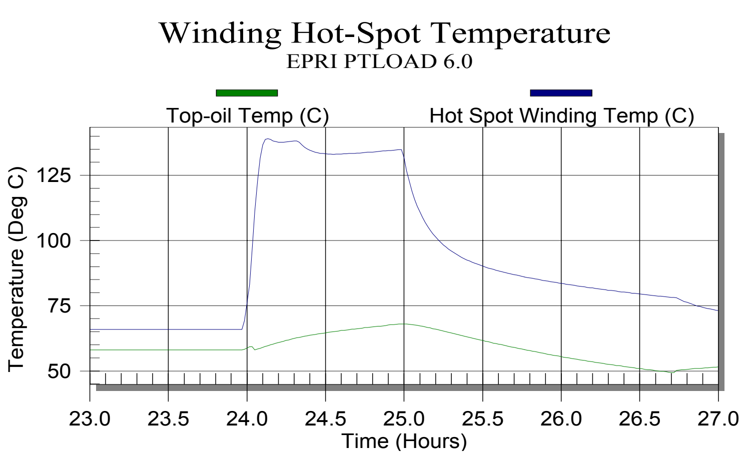
Given the very short duration of the transformer load during a DLO on Path15, the results of calculation are quite sensitive to the assumed winding thermal time constant and to the various cooling mode control options.

This section of the report provides an indication of the sensitivity of our calculation results to the assumed transformer parameters.

Cooling Mode Switching

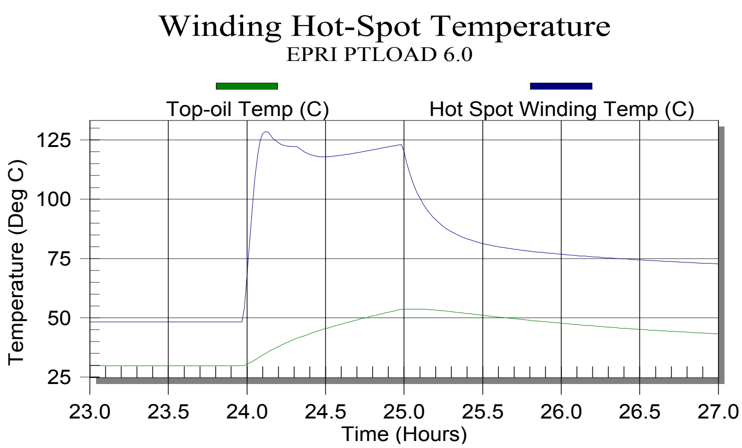
<u>Switching on Simulated Winding Hot Spot Temperature</u>

Peak Load (MVA)	= 914.43
Peak Load (Amps)	= 3975.782
Peak Load (PU)	= 2.445
Max Hot Spot (Deg C)	= 138.9782
Max Top Oil (Deg C)	= 68.02213
Max Hot Spot Oil (Deg C)	= 107.8743
Max Top Duct Oil (Deg C)	= 107.8743
Max Bottom Oil (Deg C)	= 56.6408
Peak Age Accel Factor	= 15.68519
Cumulative Loss of Life (Percent)	= 0.006327544



Cooling Constrained to 3rd Cooling Mode

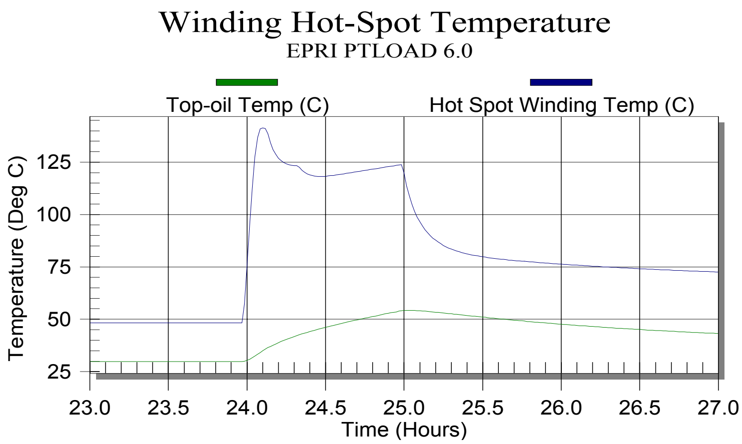
Peak Load (MVA) = 914.43
Peak Load (Amps) = 3975.782
Peak Load (PU) = 2.445
Max Hot Spot (Deg C) = 128.3642
Max Top Oil (Deg C) = 59.76436
Max Hot Spot Oil (Deg C) = 95.68692
Max Top Duct Oil (Deg C) = 95.68692
Max Bottom Oil (Deg C) = 52
Peak Age Accel Factor = 5.992945
Cumulative Loss of Life (Percent) = 0.001803935



Winding Thermal Time Constant

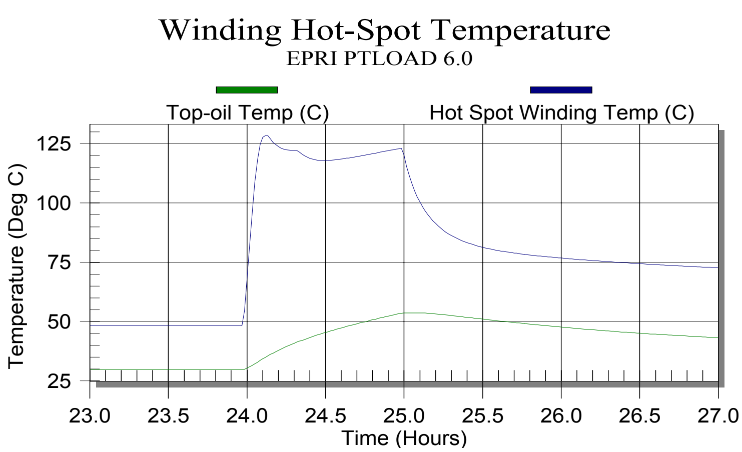
<u>5 min winding time constant (note that switching is manual constrained to third cooling mode)</u>

Peak Load (MVA) = 914.43
Peak Load (Amps) = 3975.782
Peak Load (PU) = 2.445
Max Hot Spot (Deg C) = 141.3218
Max Top Oil (Deg C) = 59.76585
Max Hot Spot Oil (Deg C) = 98.211
Max Top Duct Oil (Deg C) = 98.211
Max Bottom Oil (Deg C) = 52
Peak Age Accel Factor = 19.26932
Cumulative Loss of Life (Percent) = 0.002468203



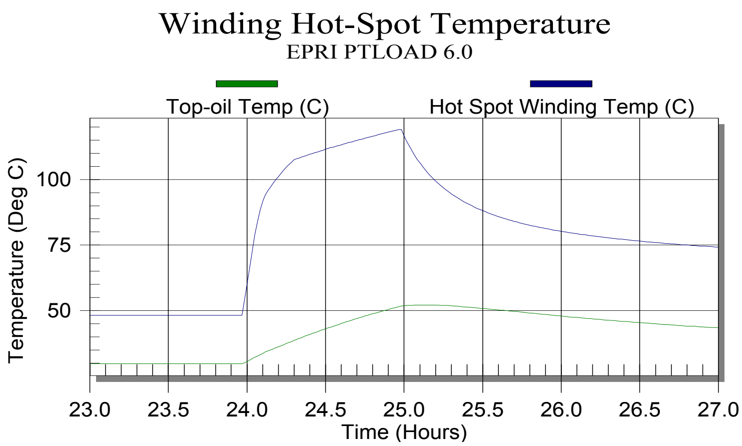
Calculated 6.77 min time constant

Peak Load (MVA) = 914.43
Peak Load (Amps) = 3975.782
Peak Load (PU) = 2.445
Max Hot Spot (Deg C) = 128.3642
Max Top Oil (Deg C) = 59.76436
Max Hot Spot Oil (Deg C) = 95.68692
Max Top Duct Oil (Deg C) = 95.68692
Max Bottom Oil (Deg C) = 52
Peak Age Accel Factor = 5.992945
Cumulative Loss of Life (Percent) = 0.001803935



15 min time constant (used in Harold Moore's report)

Peak Load (MVA) = 914.43
Peak Load (Amps) = 3975.782
Peak Load (PU) = 2.445
Max Hot Spot (Deg C) = 118.9749
Max Top Oil (Deg C) = 59.67421
Max Hot Spot Oil (Deg C) = 92.53191
Max Top Duct Oil (Deg C) = 92.53191
Max Bottom Oil (Deg C) = 52
Peak Age Accel Factor = 2.449878
Cumulative Loss of Life (Percent) = 0.0009285661



8 SOFTWARE IMPLEMENTATION OF EXTENDED PATH15 DYNAMIC THERMAL MODEL

The Gates transformer thermal modeling is to be implemented in a modified version of the software developed for the original Path 15 Dynamic Line Rating (Path15DLR) software developed in an earlier project. The basic transformer thermal modeling algorithms are implemented using the same code that is used by EPRI's PTLoad and DTCR software packages. This code, in the form of a dynamic link library (TML4.dll), enables the use of completed and tested software, in lieu of developing this portion from scratch.

In order to use the Thermal Model Library (TML4.dll) in software written and compiled using other software packages, it was decided that a COM wrapper (TMLEXE1.EXE) should be developed, such that the TML can be used in any COM-aware software package (anything from Microsoft Visual C++ to Excel). The transformer parameters required for the calculation are entered in standard ASCII files in a format compatible with both PTLoad and DTCR. These files, known as element definition files, allow a transformer to be first modeled in PTLoad, and then used in the custom Path15DLR software, without having to re-develop complex Graphical User Interfaces (GUIs) to allow for the creation of a transformer model. A general diagram detailing this approach is shown below in Figure 8-1.

In Figure 8-1, it can be seen that the real-time SCADA data (line currents, weather conditions, line tensions, etc.) is supplied to the PATH15DLR program through a dedicated PG&E database called RTScadaNT. The main program accepts the real-time data from the Path15DLr database and supplies the real-time data pertinent to the calculation of the Gates power transformer rating to the DTCR/PTLOAD library through the TMLEXE1.EXE custom software. Calculation results from DTCR/PTLOAD are sent back to the main PATH15DLR program through the same interface.

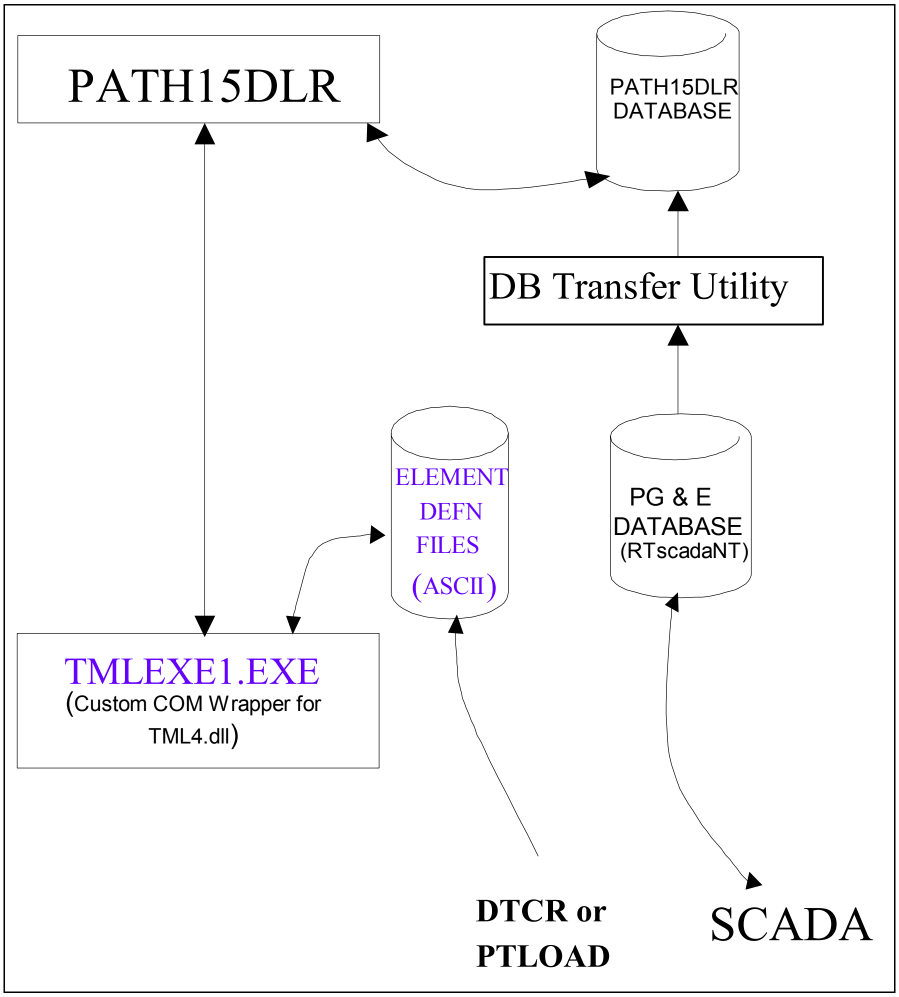


Figure 8-1
Path15 software flowchart

TMLEXE1.EXE is not a general-purpose COM server, but a specific server dedicated to the particular requirements of adding transformer limitations to the program PATH15DLR.

The PATH15DLR software has a loop in which a load multiplier is varied to find the largest value that doesn't violate thermal constraints. This multiplier affects not only the contingency load profile, but also the pre-contingency profile, both in a non-linear fashion.

Inside this loop, the program was modified to call a function in TMLEXE1.EXE to determine whether a given preload and contingency profile violate the transformer constraints. TMLEXE1 returns the following values for this assessment:

- The maximum winding hot spot temperature (deg C) from the time of contingency onset until the end of input data.
- The maximum top oil temperature for the same period.
- The cumulative loss of insulation life for the same period.

- The maximum excess bubble pressure in mmHg for this period.

If any of the above criteria violate the transformer constraints, the Path 15 transfer limit is iteratively reduced until all criteria are within the given constraints. The result is a Path 15 transfer limit such that neither the 230kV lines nor the Gates transformers are thermally overloaded in the event of the loss of the two 500kV lines. As discussed previously, voltage and/or stability constraints may also be important and should be introduced in future versions of the software.

9
FIELD TEST RESULTS

In the initial Path 15 dynamic rating study, several possible limitations of the path power transfer were identified. Of the thermal limitations, it was determined that the most often encountered limitation was that of the two 230kV lines from Gates to Panoche. The dynamic thermal rating of these lines was the focus of the original project, culminating in the development of the Path15DLR program.

As a follow-on to that project, the capability to model the thermal limitations of the Gates transformers was added to the Path15DLR program. The modified Path15DLR program (version 1.1) was installed at PG&E in May of 2002, and after several months of data transfer problems in various areas of the data collection process, the program provided reasonable results beginning in January of 2003. The following analysis is based upon data collected from 9 January, 2003 to 24 January, 2003.

Throughout the two-week period during which valid data was collected, the Gates transformers were rarely limiting. Of the 39,596 data points (30 sec. intervals), the Gates transformers only reached the limiting hot spot temperature of 140C for 52 data points, or 0.13% of the time. The majority of the time, the Gates transformers only reach 90-105C hot spot during the simulated contingencies.

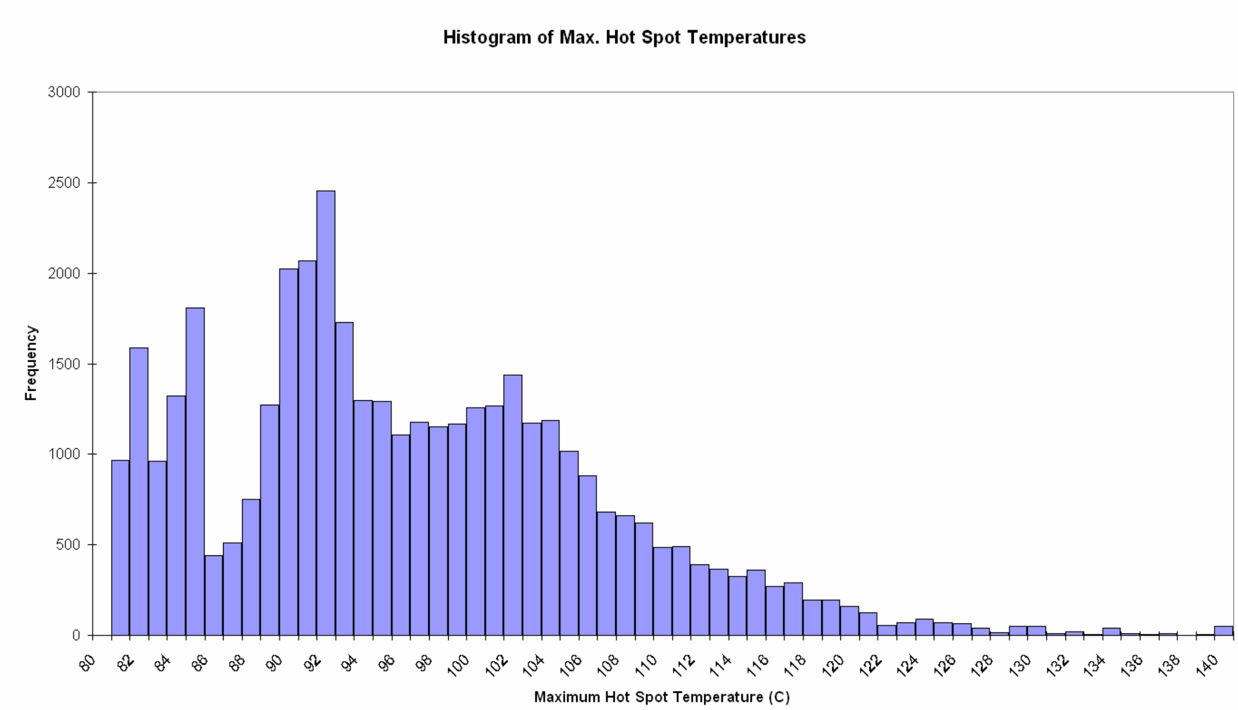


Figure 9-1
Transformer winding hot spot temperature attained with Gates-Panoche line at 100°C.

By plotting the Path 15 transfer limit calculated with and without the Gates transformer limit, it can be seen that the Gates transformer rarely limits the path flow. In the figure below, the Gates transformers are limiting in the areas where the pink shows up over the blue.

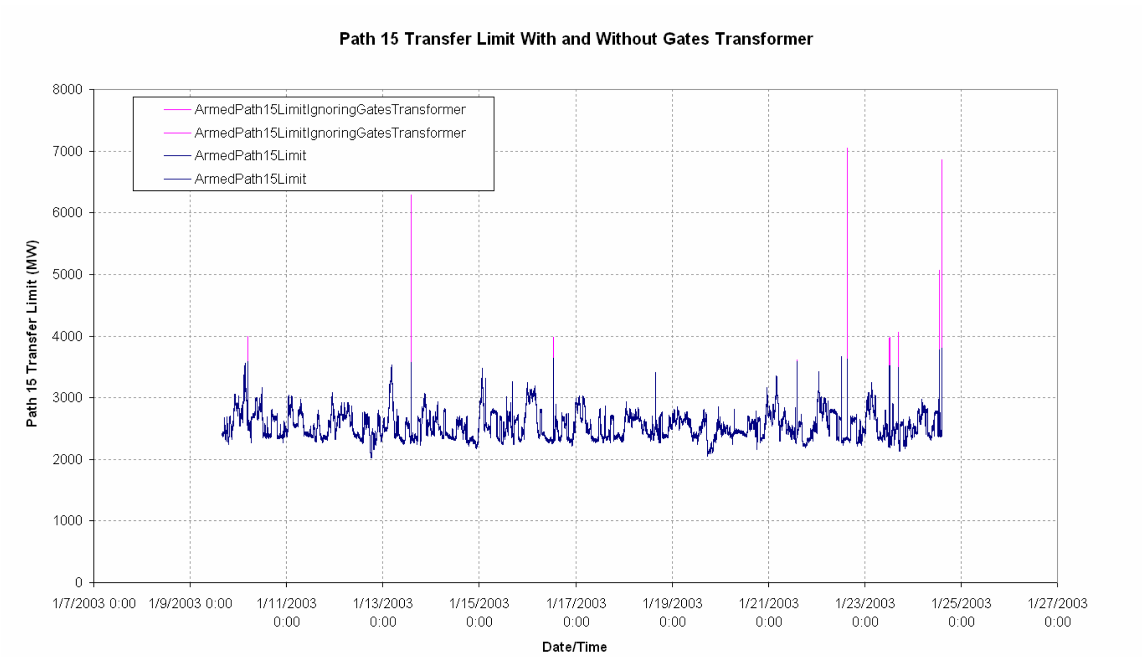


Figure 9-2
Path15 rating showing occasional high values

Given that the Gates transformer is limiting only when the Path 15 limit spikes abruptly, it would appear that something is artificially driving the Path 15 limit (as calculated considering only the 230kV lines) upward. Looking more closely at the data reveals that effective wind speed, as calculated from the tension of the 230kV lines, is unrealistically higher during the periods that the Gates transformers limit the path rating. This is shown in the plot below, where the spikes in the wind speed (light blue) correspond to the areas where the Gates transformer limits (pink).

Off-line Verification of Field Test Data

To verify the accuracy of the calculation results, several data points were selected and compared to "hand calculations" implemented via an Excel spreadsheet. In all cases, the results calculated by the Path15DLR program were within 1% of the results from the Excel spreadsheet. In addition, one point was selected, and the simulated contingency was calculated and entered into PTLoad. The installation of transformer temperature monitoring devices would be very helpful in verifying the correct modeling of the Gates transformer under a variety of system and environmental conditions.

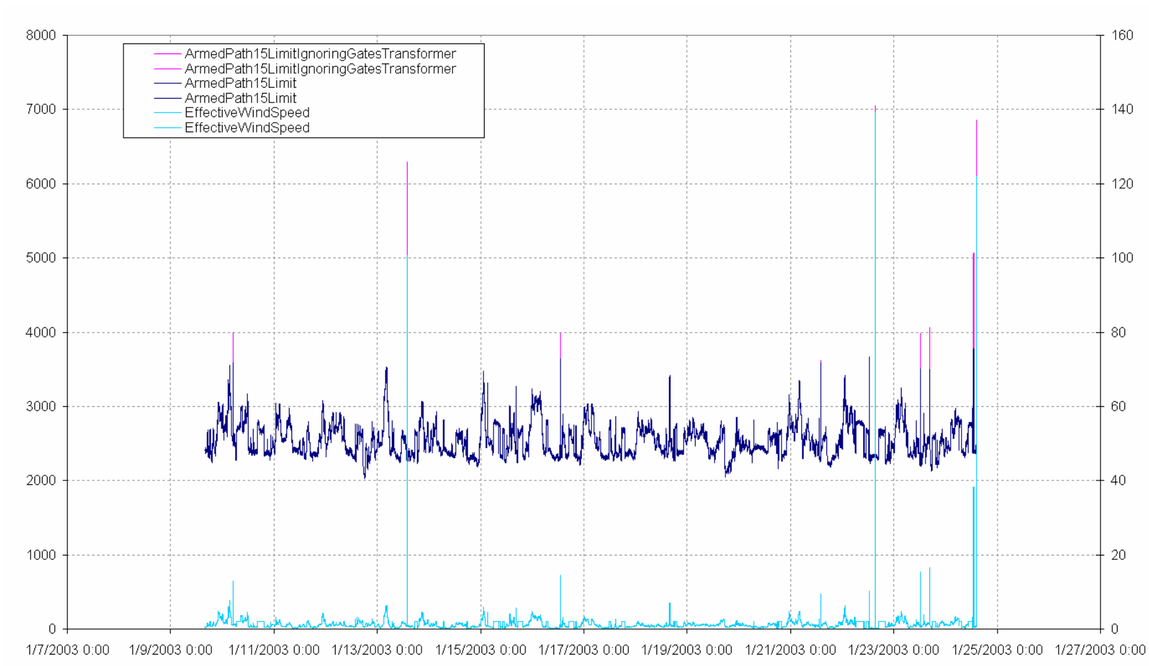


Figure 9-3
Path 15 rating and corresponding minimum effective wind speed along the 230kV lines (The Gates transformer determines the Path 15 rating when the wind speed is high).

The sample load profile for the simulated contingency is shown in the figure below, with the salient points labeled.

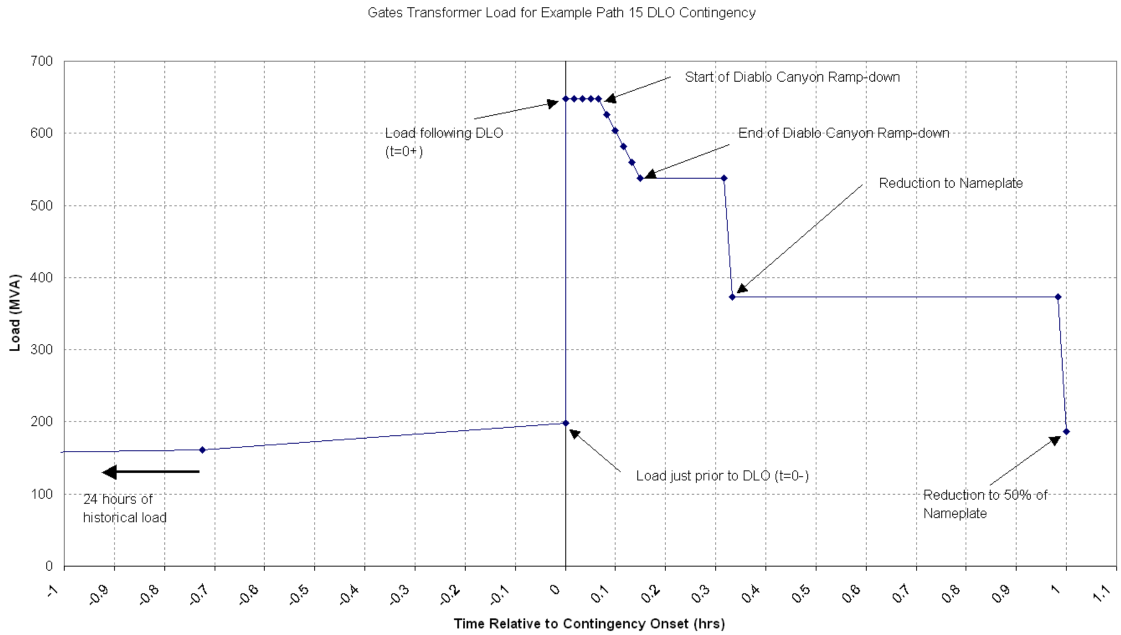


Figure 9-4
Load profile for off-line calculations in PTLOAD

The above load profile was entered in PTLoad, along with the historical ambient data. The transformer parameter ("TRA") file used in the Path15DLR program was imported into PTLoad to provide the transformer parameters. The calculation was then performed, giving the transformer temperatures shown in the plot below. The PTLoad simulation showed a peak hot spot temperature of 110.2C. The Path15DLR program reported a result of 110.3C for this same time period. In addition, the temperature profiles appear reasonable and show no unexpected behavior.

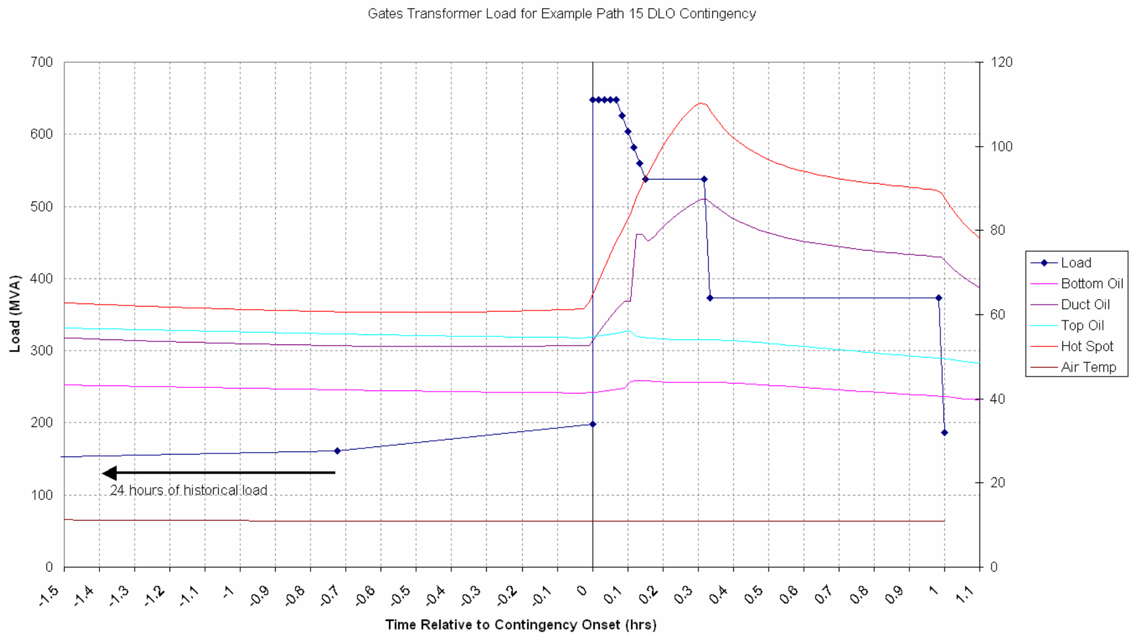


Figure 9-5
Transformer temperatures calculated with PTLOAD

In summary, data was collected from the Path15DLR program from 9JAN2003 to 24JAN2003. Analysis of this data showed that the Gates transformers rarely limited the Path 15 rating. In the instances that the Gates transformers limit the path rating, it appears as though the wind speed from tension was producing unrealistically high 230kV line ratings. Finally, the accuracy of the results was verified using hand calculations and PTLoad. Due to the criticality and cost of high voltage power transformers such as the Gates unit, the installation of temperature monitors and cooling mode indicators would help verify the correct modeling of the unit and the proper operation of active cooling devices. Ideally, the monitor data should be made available to the software for direct on-line comparisons.

10
APPLYING DYNAMIC RATING MODELS ELSEWHERE

Given the successful application of real-time, operational dynamic thermal rating technology to increasing the power flow limits on Path15, the contractors considered other implementations of this technology in California.

Certainly, line tension monitors are applicable to other critical overhead transmission lines and the EPRI DTCR models are applicable to other power transformers or underground cable circuits where improved modeling might relieve real-time operational power flow constraints. The techniques described in detail in this project and the preceding CEC project, can serve as a guideline for custom software development and testing.

The present inability to forecast or predict real-time ratings is a major impediment to other implementations of dynamic modeling within the California transmission system. The greatest difficulty in the use of the Path15 dynamic rating model centers on the variability of the power flow thermal and stability limits and the limitations that this places on the system operator's ability to utilize the results.

Beyond the challenges with regard to forecasting, additional business implementation challenges may include:

1. Analysis of the impacts of failures of dynamic rating equipment components and associated impacts on the operation of the transmission system. This can be used to develop overall design schemes.

2. Operational procedures, protocols and information exchange required between owners and operators

3. Equipment redundancy, accuracy and maintenance procedures and requirements.

4. Locating lines that are only thermally limited to gain more actual experience with these tools. More work is needed to incorporate system stability limits into the models. A thermally limited wind generation outlet may be more appropriate due to similar forecasting issues or other thermally limited local transmission lines.

5. Determining processes and procedures for transmission owner/operators and ISO/RTO's to use this tool in the forward markets and in contingency management situations. There are significantly different business benefits/consequences to the above two areas of use.

6. Future changes to system capacity or configuration which may impact the operational or economic need or viability of the technology

Given the need to forecast or predict ratings, the contractors developed the following initial evaluation of predictive techniques applicable to dynamic thermal model calculations.

11
SHORT AND LONG-TERM FORECASTING – SUMMARY

Critical to an effective forecasting algorithm is an intelligent algorithm with enough capability to capture and analyze every single change in input data and flow the change between appropriate subroutines, and eventually update the thermal rating. There are some sophisticated methods to perform the forecasting but the main considerations in this study were ease of implementation and online application.

Because of the complications of the study, the study differentiated short-term and long-term thermal rating forecasting. Short-term forecasting determined by a comprehensive analysis of line thermal ratings, using Box-Jenkins's Auto Regressive Integrated Moving Average (ARIMA) method. This method provides a comprehensive statistical modeling methodology that is the most reliable and the least expensive way of online short-term forecasting. ARIMA is capable of systematically analyzing the correlations among observed data to derive models through a sequence of stages. The final model consists of components that indicate the areas of significant correlations, whereas the model parameters capture the magnitudes of these correlations.

The complex nature of the long-term forecasting will demand more than just statistical analysis for modeling the line behavior. The long-term prediction of the events such as line thermal rating requires the process of learning the behavior of the event. During this process all the influential parameters and the probability of that their occurrences have to be organized in a robust infrastructure. The influential parameters may either be quantified or qualified parameters.

"Belief Networks"

The long-term section of this study concentrates on inducing graphically appealing probabilistic models from quantified and qualified data called Bayesian (belief) Network, and using these models to make predictions and reason about the line thermal rating. The raison d'etre for belief networks is to efficiently represent the data in a set of conditional probabilities, based on the independence assumptions characterized by the graphical layout (the Network Assumption).

This approach requires several significant requirements to be able to build such network that can be accurately responsive to the change of the events. The long-term forecasting study of this report is more involved in methodology of forecasting rather than an algorithm for forecasting. However the long-term forecasting study of this research provides an algorithm but the complexity of algorithm and the requirements of the algorithm will not allow simple implementation.

The difficulties left to the field of long-term forecasting is significant and will grow as the accuracy of the outcome rises. In solving this problem nothing helps but further understanding of the methodologies behind the rational intelligence.

A

APPENDIX – SOFTWARE DESIGN DOCUMENT

Software Design Document

For

Path15 Dynamic Line Rating (Path15DLR 1.1)

Prepared for

Power Delivery Consultants

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Ballston Lake, NY 12019

Project Manager: Dale Douglass

Prepared by

Sundaram Sethu, Best Systems
Dale Douglass, PDC
N. Dag Reppen, NPC
April 18, 2002

Introduction

This document is a Software Design Document (SDD) for the "Path15 Dynamic Line Rating " or "Path15DLR". The purpose of this document is to clearly specify the software design so that a software developer can implement a fully functional client/server based software application. This document must be read in conjunction with the Requirements Specification Document (RSD).

Path15DLR is an application designed to dynamically calculate the maximum possible power (Path15 limit) that can be safely transferred through the transmission lines comprising Path15 by considering all the factors that effect power transfer in its calculations. The first version of this application, Path15DLR 1.0, which is designed as a Windows NT service calculates new Path15 limit every 30 seconds and is already running at PG&E. In this project Path15DLR 1.0 will be modified to include the real time thermal rating of the Gates 500/230kV power transformer in its path15 limit calculations.

Sections 2 and 3 describe the design of Path15DLR 1.0. Section 4 describes the changes required in the design of path15DLR 1.0, to include the real time thermal rating of the Gates 500/230kV power transformer.

Effective Wind Speed Calculation

This section of the SDD describes the method to compute the EffectiveWindSpeed. It uses data from the CAT1File table in the database and the ConductorData.

It is assumed that only one record in the ConductorData table will contain valid conductor data. In this table the valid row only will have the DateDeleted field set to NULL value. All other rows will have this field set to a not NULL value.

Input Values

This section describes the input values used by this calculation. All the input values are retrieved from the database.

The record in the table RAS_SCADA_CAT1 will point to one record to be retrieved from each table, RASFile, RASAction, SCADAFile, and CAT1File. But this computation requires only the CAT1File and ConductorData table.

EffectiveConductorTemperature (Tc), SolarTemperature (Ts), and EffectiveCurrent (Ie)

When the PathLimit caculator program runs it will determine the first record in the ConductorData table in the database that has its DateDeleted field set to NULL value.

Four values for effective conductor temperature (Tc) can be found in the CAT1File table, namely, EffectiveConductorTemperatureNorthLine1 (TcN1), EffectiveConductorTemperatureNorthLine2 (TcN2), EffectiveConductorTemperatureSouthLine1 (TcS1), and EffectiveConductorTemperatureSouthLine2 (Tcs2)

Two values for solar temperature (Ts) can be found in the CAT1File table, namely, SolarTemperatureNorthCat1 (TsN) and SolarTemperatureSouthCat2 (TsS). Note that here the numbers 1 and 2 do not refer to the circuit numbers, but the CAT device numbers.

Two values for EffectiveCurrent (Ie) can also be found in the CAT1File table, namely, EffectiveCurrentLine1 in circuit 1 (Ie1) and EffectiveCurrentLine2 in circuit 2 (Ie2).

VWDef = Globals.DefaultWindSpeed in feet/sec (example 2 ft/sec)

IlineMin = Globals.MinimumValidLineCurrent in Amps (example 200 Amps)

Before going to the calculation of effective wind speed, check to be sure that at least one of the two effective currents (Ie1 or Ie2) exceeds the user settable minimum current (IlineMin):

If both currents exceed the minimum (IlineMin) then go on to calculate the four wind speeds Vwa, Vwb, Vwc and Vwd (Vwa is computed using TcN1, TsN, and Ie1; Vwb is computed using TcS1, TsS, and Ie1; Vwc is computed using TcN2, TsN, and Ie2; Vwd is computed using TcS2, TsS, and Ie2). Use the calculations described in sections 2.2 to 2.6

If one of the two current exceeds the minimum (IlineMin) then calculate two wind speeds, Vwa & Vwb (if Ie1 > Ilinemin) or Vwc & Vwd (if Ie2 > Ilinemin) (Vwa is computed using TcN1, TsN, and Ie1; Vwb is computed using TcS1, TsS, and Ie1; Vwc is computed using TcN2, TsN, and Ie2; Vwd is computed using TcS2, TsS, and Ie2). Use the calculations described in sections 2.2 to 2.6

If neither of the effective currents exceeds the minimum (IlineMin) then set the effective wind speed to default wind speed (VWDef) and skip the calculation of effective wind speed. Pick the smallest value from TcN1, TcN2, TcS1, and TcS2 as the Tc. Pick the largest value from TsN and TsS+ as the Ts. Ie will not be used, in this case, so there is no need to set it

[Note: Make sure that Tc>= Ts>=-273. Else report an error].

ConductorData

When the PathLimit calculator program runs it will determine the first record in the ConductorData table in the database that has its DateDeleted field set to NULL value.

Emissitivity, e = ConductorData. Emissitivity

OutsideDiameter, ODin = ConductorData. OutsideDiameter in inches

$$\text{ResistanceAt25, Rac25C} = \frac{\text{ConductorData.ResistanceAt25}\,\mathit{inOhms/mile}}{5280} \cdots \mathit{inOhms/foot}$$

$$\text{ResistanceAt75, Rac75C} = \frac{\text{ConductorData.ResistanceAt75}\,\mathit{inOhms/mile}}{5280} \cdots \mathit{inOhms/foot}$$

Elevation z = ConductorData.Elevation in ft

Total Heat Capacity mCp = (ConductorData.MCp for core + ConductorData.MCp for outer layer) in W-sec/ft-C

Make sure Rac25C > Rac75C > 0

Before Wind speed Calculations

If Tc is equal to Ts, then wind speed is zero and if Tc < Ts then wind speed cannot be calculated for this data set.

Heat Loss and Temperature Calculations

TcK = Tc + 273 in Kelvins

TsK = Ts + 273 in Kelvins

Rac @ Effective Conductor Temperature, RacTc =
Rac25C+((Tc-25)/50)*(Rac75C-Rac25C) in Ohms/foot

Make sure RacTc > 0 else report error in results.

Ohmic Heating, I2R = RacTc * (Ie^2)/5280 in w/ft

Radiation Heat Loss, Qr =
e * ODin * 0.138 * ((TcK^4)-(TsK^4))/(100^4) in w/ft

Forced Convective Heat Loss, Qc =
I2R – Qr in w/ft

PI = 3.14159

Film temperature of air in the boundary layer, Tf =
= (Tc + Ts) / 2 in degC

Air Property Calculations

Thermal conductivity of air, Kf, at the film temperature, Tf =

$$0.007388 + 2.27889 * 10^{-5} * T_{film} - 1.34328 * 10^{-9} * T_{film}{}^{2}$$

in w/ft-C

Viscosity of air, µf, at the air temperature, Ta =

$$\frac{0.00353 * (T_f + 273)^{1.5}}{(T_f + 383.4)}$$

in w/ft^3

Air density, ρf =

(0.080695 – (0.2901 * 10^{-5} *z) + (0.37 * 10^{-10} * z^2))
/ (1 + (0.00367 * Tf)) in w/ft^3

Natural Convective Heat Loss Calculation

Natural Convective heat loss =

0.0283 * (p_f ^ 0.5) * (ODin ^ 0.75) * ((Tc - Ts) ^ 1.25) in w/ft

If (Natural Convective heat loss > Qc)

Effective wind speed, Vw = 0.00 in ft/sec

Wind speed Calculations

$$\frac{\left\{\frac{\left[\left(\frac{Q_c}{K_f * (T_c - T_s)}\right) - 1.01\right]}{0.371}\right\}^{\frac{1}{0.52}} * \left(\frac{\mu_f}{OD_{in} * p_f}\right)}{3600}$$

Wind Speed, Vw1 =

in ft/sec

Wind Speed, Vw2 =

in ft/sec

Thus resultant Wind Speed, Vw = minimum of Vw1 and Vw2 for the input values of Tc, Ts, and Ie.

Effective Wind speed

$$\frac{\left\{\frac{\left[\left(\frac{Q_c}{K_f * (T_c - T_s)}\right)\right]}{0.1695}\right\}^{\frac{1}{0.60}} * \left(\frac{\mu_f}{OD * p_f}\right)}{3600}$$

The effective wind speed Vw is computed by picking the minimum of Vwa, Vwb, Vwc, and Vwd. The corresponding values of Tc, Ts, and Ie that are used to compute the particular Vwn (where Vwn is Vwa/Vwb/Vwc/Vwd) will be the effective conductor temp, effective solar temp, and effective current.

PathLimit Calculation

This section of the SDD describes the method to compute the EffectiveWindSpeed. It uses data from the CAT1File table in the database and the ConductorData.

Input Values

This section describes the input values used by this calculation. All the input values are retrieved from the database.
The record in the table RAS_SCADA_CAT1 will point to one record to be retrieved from each table, RASFile, RASAction, SCADAFile, and CAT1File. One very useful data that is retrieved from the RASFile table is the SystemConditionCodeID field.

DistributionFactor

When the PathLimit calculator program runs it will determine the first record in the DistributionFactor table in the database that has its DateDeleted field set to NULL value and with SystemConditionCodeID == RASFile.SystemConditionCodeID. The following values are retrieved from this table

1. LODFOf500AForGatesPanocheLine, $LODF500A_{GPLine}$

LODF500B ForGatesPanocheLine, LODF500BGPLine
PTDFMonitoredLine, PTDFMonLine
PTDF500Aline, PTDF500A
PTDF500Bline, PTDF500B
The program will determine the first record in the GenerationRampEffectivenessFactor table in the database that has its DateDeleted field set to NULL value and with SystemConditionCodeID == RASFile.SystemConditionCodeID. The following value is retrieved from this table.
GenerationRampGatesPanocheLineEffectivenessFactor, OTDFGen-GPLine

GenerationRamp

When the PathLimit calculator program runs it will determine the first record in the GenerationRamp table in the database that has its DateDeleted field set to NULL value. The following values are retrieved from this table:
StartTime in minutes, tGenStart
RampRate in MW/min, mGenSlope
MaximumAction in MW, PGenMax

SCADAFile

The following values are retrieved from the table SCADAFile:
PreContingencyFlowOnMonitoredLine1, Ppremon1 in MW
PreContingencyFlowOnMonitoredLine2, Ppremon2 in MW
PreContingencyFlowOn500A, Ppre500A in MW
PreContingencyFlowOn500B, Ppre500B in MW
PreContingencyFlowOn230McCall, Ppre230M in MW

PreContingencyFlowOn230Gregg, Ppre230G in MW
PreContingencyPath15Flow, PprePath15 in MW. Note that this is the total flow through the path and my not be equal to the individual sums of the above Flows. In other words, PprePath15 may not be equal to Ppremon1+ Ppremon2+ Ppre500A+ Ppre500B+ Ppre230M+ Ppre230G.
If any of the SCADA MW values go to zero then do not perform any of the calculations (PathLimit) described in this chapter. But set a value in the Path15Results table and a corresponding bad result flag.

Constants

The following values are constants required by various calculations:

2. SquareRoot3, Sqr3 = (3 ^ 0.5)

MonitoredLine1Voltage, Vmon1 = 230 in kV (this should be stored in the database)
MonitoredLine1Voltage, Vmon2 = 230 in kV (this should be stored in the database)
Kilo = 1000.0
Maximum allowed Conductor Temperature, Tcmax = 100 deg C (this should be stored in the database)

Previous Chapter

The following variables were either loaded from the database or computed during the wind speed calculations:

3. Solar Temperature = Ts in Deg C

Effective Wind Speed = Vw in ft/sec
Wind Angle = ϕ in deg [Note: Do not use WindAngle in the calculation. Assume that wind angle is perpendicular]
Conductor Emissitivity = e
ResistanceAt25 = Rac25C in Ohm/ft (divide by 5280)
ResistanceAt75 = Rac75C in Ohm/ft (divide by 5280)
Elevation = z in ft
Effective Conductor temperature = Tc deg C (from CAT1File table). This will be used as a starting conductor temperature. This is the temperature when the precontingency flow, flows through the monitored lines 1 and 2.
Emissitivity = e
OutsideDiameter = ODin in inches
Total Heat Capacity = mCp in W-sec/ft-C [Note: Heat capacity is the sum of two heat capacities in the database]

Calculate Power due to RASAction(Armed) and RASAction(All Available)

The effectiveness factor table in the database will give us the Excel sheet “RAS OTDF”. From this table we get the EffectivenessFactor or the OTDFRAS-GPLine for a bus at a given system condition. This table is more or less static as shown below:

	C00	C01	C02	C03
	No Maintenance	Panoche Gates2	LB Panoche	Henri Gregg
BUS	$OTDF_{RAS\text{-}GPLine}$	$OTDF_{RAS\text{-}GPLine}$	$OTDF_{RAS\text{-}GPLine}$	$OTDF_{RAS\text{-}GPLine}$
30057	-0.1144	-0.1617	-0.1114	-0.1329
30555	0.1022	0.1445	0.0996	0.1185
31346	0.1011	0.1430	0.0985	0.1172
31348	0.1011	0.1430	0.0985	0.1172
31354	0.1011	0.1430	0.0985	0.1172
31356	0.1011	0.1430	0.0985	0.1172
31357	0.1011	0.1430	0.0985	0.1172
31360	0.1011	0.1430	0.0985	0.1172
31364	0.1011	0.1430	0.0985	0.1172
31368	0.1011	0.1430	0.0985	0.1172
31384	0.1011	0.1430	0.0985	0.1172
31387	0.1011	0.1430	0.0985	0.1172
31958	0.1007	0.1425	0.0981	0.1167
31996	0.1007	0.1425	0.0981	0.1167
32002	0.1007	0.1425	0.0981	0.1167
32008	0.1007	0.1425	0.0981	0.1167
32010	0.1007	0.1425	0.0981	0.1167
32164	0.1007	0.1425	0.0981	0.1167
32250	0.0958	0.1355	0.0934	0.1136

The tables RASFile, RASAction, and the EffectivenessFactor tables when joined will result in a table as shown below (say for a system condition of C00):

BUS	Armed	Available	$OTDF_{RAS-GPLine}$	Armed = Armed * $OTDF_{RAS-GPLine}$	Available = Available * $OTDF_{RAS-GPLine}$
34600	0	0	0.0319	0	0
34602	0	0	0.0319	0	0
35004	70	70	-0.1129	-7.903	-7.903
35004	70	70	-0.1129	-7.903	-7.903
35004	70	70	-0.1129	-7.903	-7.903
35024	30	30	-0.1121	-3.363	-3.363
35026	0	45	-0.1123	0	-5.0535
35026	0	45	-0.1123	0	-5.0535
35026	0	45	-0.1123	0	-5.0535
35026	0	40	-0.1123	0	-4.492
35032	20	20	-0.1064	-2.128	-2.128
35038	33	33	-0.1071	-3.5343	-3.5343
35038	45	45	-0.1071	-4.8195	-4.8195
38730	0	-25	0.1244	0	-3.11
38730	0	-25	0.1244	0	-3.11
38735	0	-25	0.1244	0	-3.11
38735	0	-25	0.1244	0	-3.11
38740	0	-25	0.1244	0	-3.11
38740	0	-25	0.1244	0	-3.11
38745	0	-25	0.1244	0	-3.11
38745	0	-25	0.1244	0	-3.11
		Total =		**-37.5538**	**-82.0863**

The total in the column Armed will give the $P_{RASArmed-GPLine}$ and the total in the column Available will give the $P_{RASAvailable-GPLine}$. It is to be noted that $P_{RASArmed-GPLine}$ and $P_{RASAvailable-GPLine}$ are negative numbers. The generator has a negative effectiveness factor and a positive power value while the load has a positive effectiveness factor and a negative power value.

Initialize Variables for Monitored Line1 and Monitored Line2 Calculation for $P_{RASArmed\text{-}GPLine}$

Initial Current, I_1 =
(Ppremon1 * Kilo) / (Sqr3 * Vmon1)

Guess Initial Conductor temperature, T_1 = Tc in deg C

Initial Current, I_2 =
(Ppremon2 * Kilo) / (Sqr3 * Vmon2)

Guess Initial Conductor temperature, T_2 = Tc in deg C

Initial Steady State Temperature for Monitored Line1 and Line2 Calculation for $P_{RASArmed\text{-}GPLine}$

Init_Temp is a function with I1 and T1 as two parameters. It is used to compute the steady state temperature of the monitored line before DLO when the power through the monitored line is constant.

Make sure T1 >= Ts.

Conductor Resistance Rc = $R_{ac25} + \left(\frac{R_{ac75} - R_{ac25}}{75 - 25} \right) * \left(T_1 - 25 \right)$ in Ohms/ft

Radiative Heating q_r = $0.138 * OD_{in} * e * \left[\left(\frac{T_1 + 273}{100} \right)^4 - \left(\frac{T_s + 273}{100} \right)^4 \right]$ in W/ft

Air Film Temperature, $T_{film} = (T_1 + T_s) * 0.5$ deg C

Density of Air in lb/ft3, $\rho f = (0.080695 - (0.2901 * 10^{-5} * z) + (0.37 * 10^{-10} * z^2)) / (1 + (0.00367 * T_{film}))$

Absolute Viscosity of Air in lb/ft-h, μf =

$\frac{0.00353 * (T_f + 273)^{1.5}}{(T_f + 383.4)}$ or

$0.0415 + (1.2034 * 10^{-4} * T_{film}) - (1.1442 * 10^{-7} * T_{film}^2) + (1.9416 * 10^{-10} * T_{film}^3)$. We will use the former formula since that is as per the latest standard.

Thermal Conductivity of Air in W/ftK, Kf =

$$0.007388 + 2.27889 * 10^{-5} * T_{film} - 1.34328 * 10^{-9} * T_{film}^{\;2}$$

Forced Convection Heat Loss in W/ft for low wind speeds,

$$q_{c1} = 1.01 + 0.371 * \left(\frac{OD_{in} * \rho_f * V_w}{\mu_f} \right)^{0.52} * K_f * (T_1 - T_s)$$

Forced Convection Heat Loss in W/ft for high wind speeds,

$$q_{c2} = 0.1695 * \left(\frac{OD_{in} * \rho_f * V_w}{\mu_f} \right)^{0.6} * K_f * (T_1 - T_s)$$

Thus forced convection heat loss in W/ft, qcforced = maximum of qc1 and qc2.

Wind Angle Effect Kangle = 1 (since wind speed is perpendicular)

So qcforced in W/ft = Kangle * qcforced

Natural Convective Cooling at low wind speeds, $q_{cnatural}$=

$$0.283 * \rho_f^{\ 0.5} * OD_{in}^{\ 0.75} * (T_1 - Ts)^{1.25}$$

Total Convective Heating, q_c in W/ft = max (Forced Heating $q_{cforced}$, Natural heat loss $q_{cnatural}$) = max ($q_{cforced}$, $q_{cnatural}$)

Joule heating in W/ft, q_j = I * I * R
= I_1 * I_1 * Rc

Error = -q_c – q_r + q_j

The value of error must be < 0.01 w/ft.

If the error is not < 0.01 then repeat the above calculation with a different value for conductor surface temperature, T_1.

Thus iterating, in this manner, we get the steady state temperature of monitored line1, T1Steady. Perform a similar calculation to determine the steady state temperature of monitored line2, $T_{2Steady}$.

Calculate Monitored Line1 Current using the Flow data and $P_{RASArmed\text{-}GPLine}$

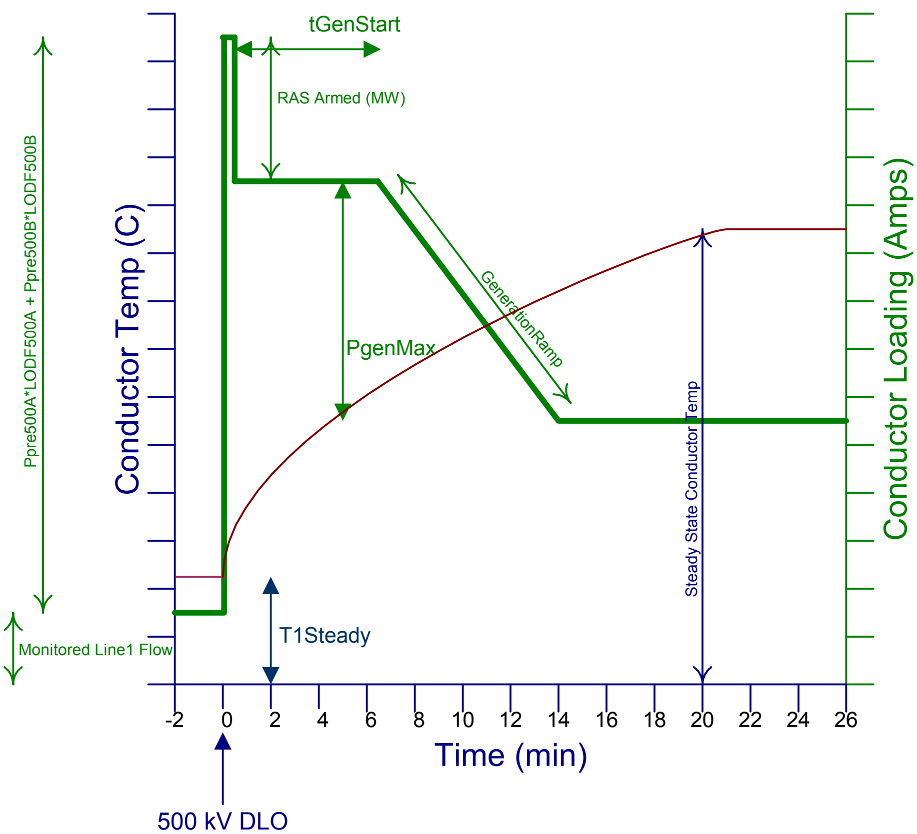

Figure 3.1 Line Rating

Using the input data from the SCADAFile, GenerationRamp, DistributionFactor, RASFile, and RASAction (Armed only) tables a plot of Powerflow through the monitored line versus time after DLO can be obtained. The equations for PowerFlow in the monitored line1 are:

4. P1(t) = Ppremon1 when t<0

P1(t) = Ppremon1 + Ppre500A * $LODF500A_{GPLine}$ + Ppre500B * $LODF500B_{GPLine}$ + $P_{RASArmed\text{-}GPLine}$ when t>=0 and t<=$t_{GenStart}$, here $P_{RASArmed\text{-}GPLine}$ is added in the equation since it is a negative number.

P_{delta} = $m_{GenSlope}$ * (t - $t_{GenStart}$). Note that time is in minutes and $m_{GenSlope}$ is in MW/min
$P_{GenMaxNew}$ = min (P_{GenMax}, (Ppremon1 + Ppre500A * $LODF500A_{GPLine}$ + Ppre500B* $LODF500B_{GPLine}$ - $P_{RASArmed-GPLine}$)/ $OTDF_{Gen-GPLine}$)
P1 (t) = Ppremon1 + Ppre500A * $LODF500A_{GPLine}$ + Ppre500B* $LODF500B_{GPLine}$ - $P_{RASArmed-GPLine}$ – ($OTDF_{Gen-GPLine}$ * P_{delta}) when t > $t_{GenStart}$ and P_{delta} <= $P_{GenMaxNew}$. Note the smallest time (t_{GenEnd}) when P_{delta} >= $P_{GenMaxNew}$. Also note that at any time P1(t) cannot be < 0.

P1(t) = Ppremon1 + Ppre500A * LODF500A + Ppre500B* LODF500B - $P_{RASArmed-GPline}$ – ($OTDF_{Gen-GPLine}$ * $P_{GenMaxNew}$) when t > t_{GenEnd}

Using the formula I1(t) = (P1(t) * Kilo) / (Sqr3 * Vmon1) we can compute the current flow through monitored line1 at any given time.

[For example if Diablo Canyon Generator drops by 150 MW, in other words P_{delta} is 150 MW, and the effectiveness factor is 0.12, then the corresponding reduction in one of the Gates-Panoche circuits is 18MW]

Calculate Monitored Line1 Transient Temperature using Equation for Current I1(t) for $P_{RASArmed}$

The transient temperature, $T_{1CurrentStep}$, depends on I_1(t) and $T_{1PrevStep}$. Initialize $T_{1PrevStep}$ to $T_{1Steady}$ for the first time in this loop and for every other step $T_{1PrevStep} = T_{1CurrentStep}$. In other words:
$T_{1PrevStep}(t) = T_{1Steady}$ when t = 0 and
$T_{1PrevStep}(t) = T_{1CurrentStep}(t-1)$ when t <> 0
Note that $T_{1PrevStep}(t)$ >= Ts

Conductor Resistance Rc = $R_{ac25} + \left(\frac{R_{ac75} - R_{ac25}}{75-25}\right) * \left(T_{1PrevStep} - 25\right)$ in Ohms/ft

Radiative Heating

q_r = $0.138 * OD_{in} * e * \left[\left(\frac{T_{1PrevStep} + 273}{100}\right)^4 - \left(\frac{T_s + 273}{100}\right)^4\right]$ in W/ft

Air Film Temperature, T_{film} = ($T_{1PrevStep}$ + T_s) * 0.5 deg C

Density of Air in lb/ft3, ρf = (0.080695 – (0.2901 * 10^{-5} *z) + (0.37 * 10^{-10} * z^2)) / (1 + (0.00367 * T_{film}))

Absolute Viscosity of Air in lb/ft-h, μf_{hr} =
$\frac{0.00353 * (T_f + 273)^{1.5}}{(T_f + 383.4)}$ or

$0.0415 + (1.2034 * 10^{-4} * T_{film}) - (1.1442 * 10^{-7} * T_{film}^{2}) + (1.9416 * 10^{-10} * T_{film}^{3})$. We will use the former formula since that is as per the latest standard.

μf_{sec} in lb/ft-sec = μf_{hr} / 3600

Thermal Conductivity of Air in W/ftK, Kf =

$$0.007388 + 2.27889 * 10^{-5} * T_{film} - 1.34328 * 10^{-9} * T_{film}^{\ 2}$$

Forced Convection Heat Loss in W/ft for low wind speeds,

$$q_{c1} = \left[1.01 + 0.371 * \left(\frac{OD_{in} * \rho_f * V_w}{\mu_{f\,\mathrm{sec}}} \right)^{0.52} \right] * K_f * \left(T_{1\mathrm{Pr}\,evStep} - T_s \right)$$

Forced Convection Heat Loss in W/ft for high wind speeds,

$$q_{c2} = \left[0.1695 * \left(\frac{OD_{in} * \rho_f * V_w}{\mu_{f\,\mathrm{sec}}} \right)^{0.6} \right] * K_f * \left(T_{1\mathrm{Pr}\,evStep} - T_s \right)$$

Thus forced convection heat loss in W/ft, $q_{cforced}$ = maximum of qc1 and qc2.

Wind Angle Effect Kangle = 1 (since wind speed is perpendicular)

So qcforced in W/ft = Kangle * $q_{cforced}$

Natural Convective Cooling at low wind speeds, $q_{cnatural}$=

$$0.283 * \rho_f^{\ 0.5} * OD_{in}^{\ 0.75} * \left(T_{1\mathrm{Pr}\,evStep} - Ts \right)^{1.25}$$

Total Convective Heating, q_c in W/ft = max(Forced Heating $q_{cforced}$, Natural heat loss $q_{cnatural}$) = max($q_{cforced}$, $q_{cnatural}$)

Joule heating in W/ft, q_j = I * I * R
= I_1(t) * I_1(t) * Rc

t_{Delta} = 0.1 minutes = 0.1 * 60 seconds = 6 seconds. This is assuming that the time step is 0.1 minutes.

$T_{1CurrentStep} = T_{1PrevStep} + (((q_j - q_c - q_r)/(mCp)) * t_{Delta)}$

$$T_{1CurrentStep} = T_{1PrevStep} + \left[\left(\frac{q_j - q_c - q_r}{mCp} \right) * t_{Delta} \right]$$ where t_{Delta} is in seconds.

Now with values for T1CurrentStep for different time we can get the temperature as a function of time. We continue to get new temperatures till all the current equations I(t) have been used and the Absolute Value of ($T1_{CurrentStep} - T1_{PrevStep}$) is < 0.01. This final value of $T1_{CurrentStep}$ is the steady state temperature of the monitored line1 for the given flow after DLO, $T_{1TransientSteady}$.

Calculate Monitored Line2 Current using the Flow data for $P_{RASArmed}$

Similar to the section "Calculate Monitored Line1 Current using the Flow data", section 3.1.9.

Calculate Monitored Line2 Transient Temperature using Equation for Current I2(t) for $P_{RASArmed}$

Similar to the previous section, "Calculate Monitored Line2 Transient Temperature using Equation for Current I2(t)", , section 3.1.10, compute $T_{2TransientSteady}$.

Calculate Monitored Line Transient Temperature for $P_{RASArmed}$

Compare $T_{1TransientSteady}$ and $T_{2TransientSteady}$ and the highest value among the two will be $T_{TransientSteady}$.

Calculate New Flows for $P_{RASArmed}$

The value of $T_{TransientSteady}$ will be used to determine the increase or decrease of PowerFlow through Path15.

Let us assume that after time = 22 minutes the net temperature of the monitored lines is computed as 70 deg C. Since we can go up to 100 deg C max, we can increase the PreContingency Flow through Path15. Let us say that we increase by DeltaP15. Now the new PreContingency flows will be:
All PTDFs must be >= 0 and DeltaP15 >= -Ppre/PTDF. So the effective DeltaP15 >= smallest of all (-Ppre/PTDF).

5. Ppremon1New = Ppremon1 + DeltaP15 * $PTDF_{MonLine}$
6. Ppremon2New = Ppremon2 + DeltaP15 * $PTDF_{MonLine}$
7. Ppre500ANew = Ppre500A + DeltaP15 * $PTDF_{500A}$
8. Ppre500BNew = Ppre500B + DeltaP15 * $PTDF_{500B}$
9. PprePath15New = PprePath15 + DeltaP15 (This is the total flow through the path)

Note that in the computations to determine the effective precontingency flow through each line, the PTDF factor is applied to the Change in PowerFlow (in Path15) and not the total power flow through Path15.

Rerun Calculations to determine Max Flow in Path15 for $P_{RASArmed\text{-}GPLine}$

Now run through the calculations again and determine the temperature of the two monitored lines. In other words repeat calculations in sections 3.1.7 to 3.1.13 and get a new value for $T_{TransientSteady}$.

If the temperature, $T_{TransientSteady}$, has not reached 100 deg C max, then continue repeating till the temperature is <= 100 deg C max. But the first thing to do is to compute the pre contingency temperatures of the monitored lines when the power flow through them is Ppremon1New and Ppremon2New using the Init_Temp calculations.

The final value of PprePath15New is the result for RASAction(Armed).

Rerun Calculations for RASAction (All Available)

This entire procedure is also repeated for RASAction (All Available) by using the value of $P_{RASAvailable\text{-}GPLine}$ instead of $P_{RASArmed\text{-}GPLine}$. In other words repeat calculations in sections 3.1.7 to 3.1.15.

Changes on Path15DLR 1.0 design

Path15DLR 1.0 design will be modified to include the Gates 500/230kV transformer ratings in its calculations. To do this Path15DLR 1.1 will use the COM wrapper for EPRI's Thermal Modal Library (TML.EXE) that performs all the transformer calculations. Path15DLR 1.1 will supply the following values as arguments to the "EvaluateProfile" function of TML.EXE.

Inputs

ScadaFile

The program uses the following values from the "SCadaFile" table.

PrecontingencyFlowOnGatesTransformer1, $Ppre_{GatesTransformer1}$

PrecontingencyFlowOnGatesTransformer2, $Ppre_{GatesTransformer2}$

PrecontingencyFlowOnGatesTransformer3, $Ppre_{GatesTransformer3}$

For calculating the pre-contingency load average the program uses the maximum of these three values, $Ppre_{MaxGatesTransformer}$.

$Ppre_{MaxGatesTransformer} = \max (Ppre_{GatesTransformer1}, Ppre_{GatesTransformer2}, Ppre_{GatesTransformer3})$

Section 3 describes the steps for calculating the maximum total power flow on Path15 before contingency, $PprePath15Limit_{BeforeGatesTransformer}$. This Path15 limit that is calculated without considering the Gates 500/230 kV transformer along with the measured value of Path15 flow, $PprePath15_{Measured,}$ retrieved from the PrecontingencyPath15Flow field of the ScadaFile table, is used to calculate the change in power flow, DeltaP as follows.

$$DeltaP = PprePath15Limit_{BeforeGatesTransformer} - PprePath15_{Measured}$$

DistributionFactor

The program determines the first record in the DistributionFactor table in the database that has its DateDeleted field set to NULL value and with SystemConditionCodeID == RASFile.SystemConditionCodeID. The following values are retrieved from this table

PTDFOfGatesTransformer, $PTDF_{GatesTransformer}$
LODFOf500AforGatesTransformer, $LODF500A_{GatesTransformer}$
LODFOf500BforGatesTransformer, $LODF500B_{GatesTransformer}$

GenerationRampEffectivenessFactor

The following value is retrieved from GenerationRampEffectivenessFactor table

GenerationRampGatesTransformerEffectivenessFactor, $OTDF_{Gen-GatesTransformer}$

CAT1File

The following values are retrieved from CAT1File table.

GatesSubstationAirtemperature, $T_{Air-GatesSubstation}$

GatesSubstationAirTemperaturvalidDataFlag

Calculate Power due to RASAction (Armed) and RASAction (All Available)

The effectiveness factor table in the database will give us the Excel sheet “RAS OTDF”. From this table we get the EffectivenessFactor or the $OTDF_{RAS-GateTransformer}$ for a bus at a given system condition. This table is more or less static as shown below:

	C00	C01	C02	C03
	No Maintenance	Panoche Gates2	LB Panoche	Henri Gregg
BUS	$OTDF_{RAS-GateTransformer}$	$OTDF_{RAS-GateTransformer}$	$OTDF_{RAS-GateTransformer}$	$OTDF_{RAS-GateTransformer}$
30057	-0.1144	-0.1617	-0.1114	-0.1329
30555	0.1022	0.1445	0.0996	0.1185
31346	0.1011	0.1430	0.0985	0.1172
31348	0.1011	0.1430	0.0985	0.1172
31354	0.1011	0.1430	0.0985	0.1172
31356	0.1011	0.1430	0.0985	0.1172
31357	0.1011	0.1430	0.0985	0.1172
31360	0.1011	0.1430	0.0985	0.1172
31364	0.1011	0.1430	0.0985	0.1172
31368	0.1011	0.1430	0.0985	0.1172
31384	0.1011	0.1430	0.0985	0.1172
31387	0.1011	0.1430	0.0985	0.1172
31958	0.1007	0.1425	0.0981	0.1167
31996	0.1007	0.1425	0.0981	0.1167
32002	0.1007	0.1425	0.0981	0.1167
32008	0.1007	0.1425	0.0981	0.1167
32010	0.1007	0.1425	0.0981	0.1167
32164	0.1007	0.1425	0.0981	0.1167
32250	0.0958	0.1355	0.0934	0.1136

The tables RASFile, RASAction, and the EffectivenessFactor tables when joined will result in a table as shown below (say for a system condition of C00):

BUS	Armed	Available	$OTDF_{RAS-GateTransformer}$	Armed = Armed * $OTDF_{RAS-GateTransformer}$	Available = Available * $OTDF_{RAS-GateTransformer}$
34600	0	0	0.0319	0	0
34602	0	0	0.0319	0	0
35004	70	70	-0.1129	-7.903	-7.903
35004	70	70	-0.1129	-7.903	-7.903
35004	70	70	-0.1129	-7.903	-7.903
35024	30	30	-0.1121	-3.363	-3.363
35026	0	45	-0.1123	0	-5.0535
35026	0	45	-0.1123	0	-5.0535
35026	0	45	-0.1123	0	-5.0535
35026	0	40	-0.1123	0	-4.492
35032	20	20	-0.1064	-2.128	-2.128
35038	33	33	-0.1071	-3.5343	-3.5343
35038	45	45	-0.1071	-4.8195	-4.8195
38730	0	-25	0.1244	0	-3.11
38730	0	-25	0.1244	0	-3.11
38735	0	-25	0.1244	0	-3.11
38735	0	-25	0.1244	0	-3.11
38740	0	-25	0.1244	0	-3.11
38740	0	-25	0.1244	0	-3.11
38745	0	-25	0.1244	0	-3.11
38745	0	-25	0.1244	0	-3.11
		Total =		**-37.5538**	**-82.0863**

The total in the column Armed will give the $P_{RASArmed-GatesTransformer}$ and the total in the column Available will give the $P_{RASAvailable-GatesTransformer}$. It is to be noted that $P_{RASArmed-GatesTransformer}$ and $P_{RASAvailable-GatesTransformer}$ are negative numbers. The generator has a negative effectiveness factor and a positive power value while the load has a positive effectiveness factor and a negative power value.

GatesTransformerFlowLimit

The program retrieves the following values from the GatesTransformerFlowLimit table from all the rows with DateDeleted==NULL.

TimeInMinutesFromContingency, $t_{FromContingency}$

FlowLimitOfGatesTransformer, P_{Limit}

Here P_{Limit} is the maximum transformer load after $t = t_{FromContingency}$.

Gates 500/230 kV Transformer Parameters

The program retrieves the following values from the Globals table.

10. MaximumAllowedHotSpotTemperature
MaximumAllowedTopOilTemperature
MaximumAllowedLossOfInsulationLifeOverContingencyPeriod
MaximumAllowedBubbleOverPressure

Arguments to the "EvaluateProfile"

ConfigurationFilename (string)

This is the path and the file name of an element definition file or TRA file. The program retrieves this value from the TransformerThermalParametersFileName filed of the Globals table in the database.

NumberOfPoints (int)

This is the number of points in subsequent arrays.

DebugFlag (int)

0 for no debug. 1 to create a new debug files each call; 2 to append to the debug file each time.

LoadArray_MVA (float)

This is an array of single-precision floats. It will contain load values from 24 hours before contingency to 48 hours after contingency. These values are calculated as described below.

The transformer load before contingency (for -24 < t < 0)

The hourly average of $Ppre_{MaxGatesTransformer}$ is taken for the past 24 hours. For example if the current time is 10.30 AM, the hourly average from 9.30 AM 10.30 AM represents the load value at time

–0.5, the hourly average from 8.30 AM to 9.30 AM represents the load value at time –1.5 and so on.

The load values for t >=0 and t < 20/60

The power flow in the monitored line 1 after contingency is calculated by the following equations.

$Ppre_{GatesTransformer} = Ppre_{MaxGatesTransformer} + DeltaP * PTDF_{GatesTransformer}$

$P(t)_{GatesTransformer} = Ppre_{GatesTransformer}$ at t = 0

$P(t)_{GatesTransformer} = Ppre_{GatesTransformer} + Ppre500A * LODF500A_{GatesTransformer} + Ppre500B * LODF500B_{GatesTransformer} + P_{RASArmed\text{-}GatesTransformer}$ when t>0 and t<=$t_{GenStart}$, here $P_{RASArmed\text{-}GatesTransformer}$ is added in the equation since it is a negative number.

$P_{delta} = m_{GenSlope} * (t - t_{GenStart})$. Note that time is in minutes and $m_{GenSlope}$ is in MW/min
$P_{GenMaxNew} = \min(P_{GenMax}, (Ppre_{GatesTransformer} + Ppre500A * LODF500A_{GatesTransformer} + Ppre500B* LODF500B_{GatesTransformer} - P_{RASArmed\text{-}GatesTransformer})/ OTDF_{GenGatesTransformer})$
$P(t)_{GatesTransformer} = Ppre_{GatesTransformer} + Ppre500A * LODF500A_{GatesTransformer} + Ppre500B* LODF500B_{GatesTransformer} - P_{RASArmed\text{-}GatesTransformer} - (OTDF_{Gen\text{-}GatesTransformer} * P_{delta})$ when $t > t_{GenStart}$ and $P_{delta} <= P_{GenMaxNew.}$ Note the smallest time (t_{GenEnd}) when $P_{delta} >= P_{GenMaxNew}$. Also note that at any time P1(t) cannot be < 0.

$P(t)_{GatesTransformer} = Ppre_{GatesTransformer} + Ppre500A * LODF500A_{GatesTransformer} + Ppre500B* LODF500B_{GatesTransformer} - P_{RASArmed\text{-}GatesTransformer} - (OTDF_{Gen\text{-}GatesTransformer} * P_{GenMaxNew})$ when $t > t_{GenEnd}$

The same way the transformer load for RAS Available is also calculated.

These load values are calculated each minute at time 1/60, 2/60 and so on till the end of the generation ramp.

The load values t >20 minutes after contingency

To calculate the load at t, the program selects the minimum of the calculated transformer load, $P(t)_{GatesTransformer}$ and the P_{Limit} at time t. Suppose the program retrieved two sets of values, (1200, 20) and (600, 60) for the ($P_{Limit,}$ $t_{FromContingency}$) pair from the database as specified in section 4.1.6. In this case the program will use the minimum of $P(t)_{GatesTransformer}$ and 1200 as the transformer load for the time duration 20 <= t <60 and the minimum of $P(t)_{GatesTransformer}$ and 60 as the transformer load for the time duration t >=60.

AmbtArray_DEGC (double)

This is an array of single-precision floats. It will contain the Gates substation air temperature values from 24 hours before contingency to 48 hours after contingency. This is calculated as described below.

The air temperature before contingency (-24 < t < 0)

The program retrieves values of GatesSubstationAirtemperature for the time duration –24 <= t < 0 from CAT1File table and calculates 24 hourly averages. For example if the current time is 10.30 AM, the hourly average of the air temperatures from 9.30 AM to 10.30 AM represents the average air temperature at time –0.5, the hourly average from 8.30 to 9.30 represents the load value at time –1.5 and so on. Only valid air temperatures (The validity is decided by the GatesSubstationAirTemperaturevalidDataFlag) are used for calculating the average.

The air temperature at contingency (At t = 0)

The current value of $T_{Air\text{-}GatesSubstation}$ is used as the air temperature at time t=0.

The air temperature immediately after contingency (0< t < 20/60)

The Gates Substation Air Temperature immediately after contingency till the end of the Generation Ramp is assumed to be the same as the Gates $T_{Air\text{-}GatesSubstation}$.

The air temperature after contingency (20/60 <= t < 48

The air temperature pattern during the 24 hours before contingency, offset by the difference between the temperature at t=0 and t = -24 is repeated for each 24 hours after contingency. That is

$T_{t=x} = T_{t=x-24} + T_0 - T_{t=-24}$, where $T_{t=x}$ is the gates Substation Air Temperature at time, t = x.

TimeArray_hrs (float)

TimeArray_hrs contains relative time like –23.5, -22.5, -21.5, … , 0, 1/60, 2/60, 3/60 till the end of generation ramp. After that the values will be at 4-hour intervals like 4,8,12 and so on.

Contingency_hr (float)

This is a single-precision float value. This value is always 0, since the calculation assumes that the contingency occurs at time 0.

Using the output parameter values of EvaluateProfile function to calculate path15 limit

The evaluate profile function returns the following values

Maximum hot spot temperature

Maximum top oil temperature

Loss of insulation life over the contingency period

Maximum bubble over pressure

The program compares these four values against their upper limits specified in section 4.1.7. If any of these values exceed their limits the program reduces the DeltaP and recalculates the inputs to the EvaluateProfile function. This process is repeated till the maximum possible Path15 limit that keeps the four output parameter values listed above below their maximum allowed values.

Changes in the Transient Steady State Temperature Calculations.

Instead of using the transient steady state conductor temperature as the criteria for deciding the Path15 limit, the program will use the maximum conductor temperature reached after the DLO.

B
APPENDIX – OVERVIEW PAPER ON INITIAL PATH15 DYNAMIC RATING PROJECT

Dynamic Thermal Rating of Path 15

An Overview of the Dynamic Rating Scheme Implemented to Enhance South to North Power Transfers in California

N. Dag Reppen, Niskayuna Power Consultants, LLC
Schenectady, NY, October 2001

Abstract

A dynamic monitoring and rating system has been implemented to determine the maximum flow allowable on Path 15, which limits the south to north power transfer in California. This paper describes the procedures and facilities employed to determine the most severe thermal limitation on this path in real time. The calculated limit, updated every 30 seconds, responds to changes in transmission line conductor ambient conditions, power flow patterns, and available remedial actions.

Abbreviations/acronyms

WSCC - Western Systems Coordinating council

PG&E - Pacific Gas and Electric Co.

RAS - Remedial Action System

DLO - A specific Double Line Outage condition

CAT-1 - Transmission Line Monitoring System

Introduction

Secure operation of the WSCC system is based on maintaining the flows on a number of defined "paths" below specified "path ratings". A "path" is defined as a group of parallel lines and is thus a kin to the term "transmission interface" used in the Eastern United States. The "path rating" may be a single number or it may be a function of the flow on other paths. In the latter case, the path rating is defined graphically in a "nomogram".

The rating of Path 15 limits the south to north flow in California and would, for example, limit the power export from the Los Angeles area to the San Francisco Bay area. The path consists of 5 parallel circuits, two series compensated 500 kV lines and four 230 kV circuits. See Fig.1.

Depending on system conditions, the path rating may be defined by one of the following limitations:

1. Overload on the 230 kV circuits from Gates to Panoche for the simultaneous loss of the two 500 kV lines of the path. This outage is referred to as the Double Line Outage (DLO) contingency.

2. Overload on the Gates 500/230 kV transformer for the DLO contingency

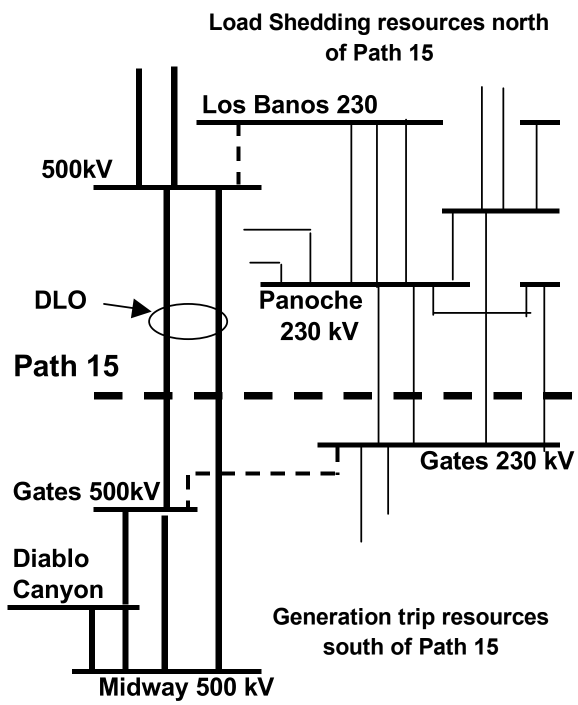

Fig.1. Structure of transmission system around Path 15.

3. Voltage problems north of Path 15 for the DLO contingency

4. Overload on the series capacitors on the 500 kV line under normal or single contingency conditions

5. Voltage problems in Idaho during the DLO contingency caused by increase in flow on the parallel path from Southern California to the Pacific Northwest via Idaho

Most frequently, the maximum flow allowed from south to north across Path 15 is limited by item 1: the thermal limitations of the Gates-Panoche lines for the loss of the two 500 kV lines. Presently, the Path 15 rating caused by this thermal limitation is maximized by the use of automatic and manual post contingency remedial actions. As indicated in Fig. 1, these actions consist of automatic load shedding north of Path 15, automatic generation trips south of Path 15, and manual run-back of the Diablo Canyon generation. The automatic action is controlled by a computerized Remedial Action System (RAS), which monitors load and generation available for shedding and tripping and automatically arms the appropriate amount of remedial action based on the telemetered flow on Path 15. The run-back of the two units at the Diablo Canyon plant is anticipated to start within 4 minutes of the DLO event. The plant output will be ramped down at a rate of 200/MW per minute for 5 minutes.

The remedial action taken will result in a post contingency loading of the Gates-Panoche lines that varies over time as shown in the top graph of Fig.2. This causes the temperature of the conductor to respond in the manner shown in the bottom graph. Note that the conductor temperature is a function of the pre-contingency temperature, the loading of the line immediately after the automatic RAS action and the gradual reduction in line loading caused by the ramp-down of the Diablo Canyon generation. The immediate post-contingency loading lasts for only a fraction of a second and will have no appreciable impact on the conductor temperature

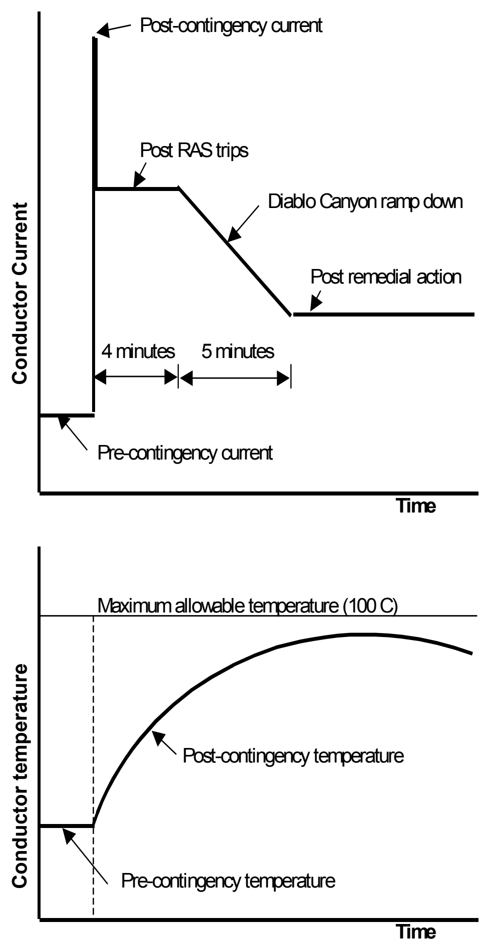

Fig. 2. Time function of conductor current and temperature of the Gates-Panoche 230 kV circuits following the loss of the two 500 kV lines on Path 15.

The maximum conductor temperature allowed for this contingency is 100 C. This is a special limit restricted to no more than 30 hours duration for the life of the conductor. Thus, the rating of Path 15 is the pre-contingency flow across Path 15 that will result in a maximum temperature of 100 C.

The conductor temperature is also a function of ambient conditions such as temperature, wind speed, wind direction, and solar radiation. Present path rating procedures recognizes the ambient impacts by using a few categories of ambient conditions that relates to ambient temperature and time of day.

The dynamic rating scheme described here improves on the present rating procedures by introducing real time monitoring of the thermal characteristics of the Gates-Panoche 230 kV circuits and by using telemetered data on the pre-contingency line flows on the Gates-Panoche lines and the two 500 kV lines on Path 15. The result of this dynamic rating process is a continually varying rating for Path 15 based on the Gates-Panoche/DLO limitation. This rating is then compared with the Path 15 ratings established for the other limitations to dynamically modify the rating nomogram for Path 15.

Dynamic rating system for Path 15

Fig. 3 provides an overview of the components of the Path 15 dynamic rating scheme for the Gates-Panoche/DLO thermal limitation.. The scheme has three main components:

1. Real time monitoring of the thermal environment of the Gates-Panoche 230 kV lines using the CAT-1 Transmission Line Monitoring System, manufactured by the Valley Group, Inc, Ridgefield Connecticut

2. Remedial action monitoring and arming designed by PG&E

3. Path 15 Rating calculator

Real time monitoring of the thermal environment of the Gates-Panoche lines

The real time monitoring component supplies the Path 15 rating calculator with the thermal environment of the conductors on the Gates-Panoche lines. It consists of three main components:

1. A device that measures conductor tension by means of a mechanical "Load Cell" inserted between the insulator and the conductor at a dead end structure. This tension is translated into an average effective temperature that determines sag and ground clearance.

2. A Net Radiation Temperature Sensor. This is a short replica of the conductor that is oriented in parallel with the line conductor but that carries no current. This replica has the same diameter and the same absorptivity as the line conductor. The monitored temperature on the sensor represents the combined effect of ambient temperature, solar heat gain, radiation, and convective cooling that would determine the temperature of the line conductor at zero electrical loading.

3. Heat balance calculations to determine the effective perpendicular wind speed existing on the span. This calculation uses the monitored effective temperature derived form the tension measurements, the zero load current temperature from the "Net Radiation Temperature" device and the line current.

In this manner, the CAT-1 Transmission Line Monitoring System provides continuously updated values for the three thermal environmental quantities required to calculate conductor currents as a function of time and time varying electrical line loading:

1. Effective conductor temperature at measured line current
2. Net Radiation Temperature for zero electrical loading
3. Effective wind speed.

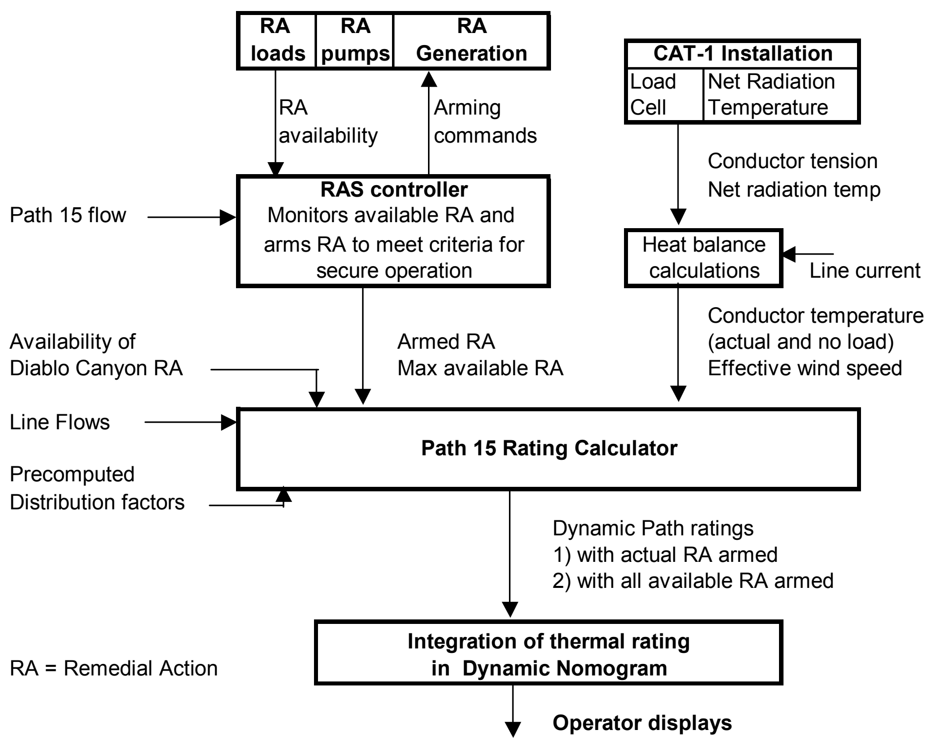

Fig. 3. Components of Path 15 real time rating system.

Remedial Actions

A computer controlled Remedial Action System (RAS) maintained by PG&E monitors the amount of load and generation that can be tripped off line in case the DLO contingency should occur. The system then arms a combination of these possible remedial actions that is deemed sufficient to maintain secure operation. The arming process is guided by precomputed factors expressing the effectiveness of each remedial action in reducing the post contingency line flow on the Gates-Panoche lines. The availability of ramp-down of the Diablo Canyon plant and the effectiveness of this remedial action are important inputs to the arming decisions.

Path 15 Rating Calculations

The Path 15 rating defined by the thermal loading on the Gates-Panoche line for the DLO contingency is determined using transient thermal calculations as shown in Fig. 4.

The Path 15 rating is calculated based on the conductor thermal parameters of the Gates-Panoche lines, updated periodically by the CAT-1 transmission line monitoring system, available and armed remedial actions received from the RAS controller and telemetered line flows for the two 500 kV lines on Path 15 and the Gates-Panoche lines. Initial calculations determine the conductor temperature as a function of time for the actual telemetered flow on Path 15. If the maximum temperature during the first 15 minutes after the contingency is different from the maximum allowable temperature (100 C), the calculation is repeated with a new value for the Path 15 flow. The Path 15 rating is the Path flow that yields a maximum calculated temperature that matches the allowable temperature.

The initial post contingency loading of the Gates-Panoche lines (Fig. 2) is calculated based on precomputed distribution factors and telemetered MW flows from the two 500 kV lines and the Gates – Panoche 230 kV lines. These telemetered flows contain all intelligence about the generation and load patterns that is needed to determine the Path 15 rating. That is, the Path rating will be continuously updated to reflect any changes in load, generation, and resulting flow patterns as they occur. The distribution factors are constants that are valid for a specific system configuration. When there is a change in the system configuration that may significantly impact the flow distribution amongst the lines of Path 15, a new set of distribution factors are applied. Significant system changes in this case are generally limited to switching of 500 kV and 230 kV lines and transformers in and around Path 15.

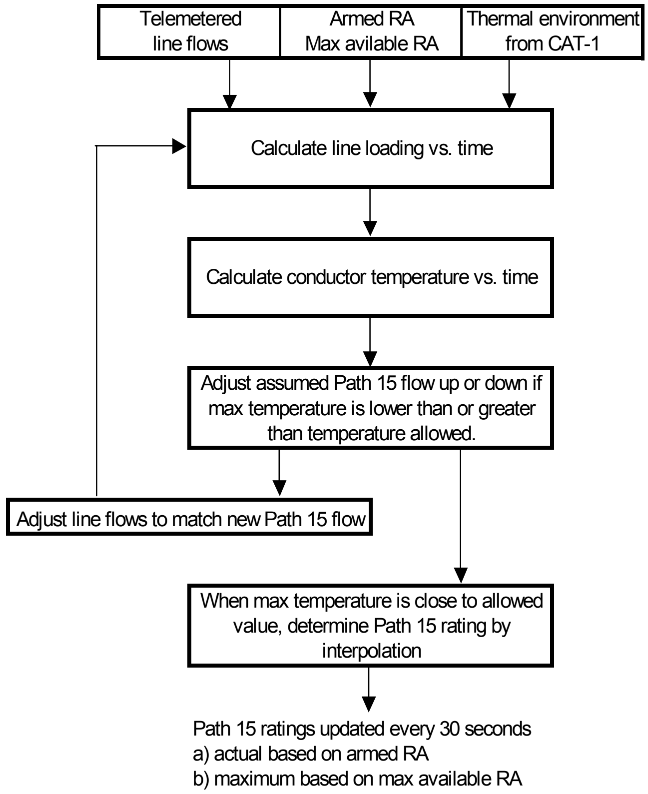

Fig. 4. Simplified flow chart of Path15 rating calculation. Ratings reflecting changes in critical line flows, environmental conditions and arming or remedial actions are updated every 30 seconds. A maximum Path rating assuming that all available remedial actions are armed, are also calculated.

The impact of the remedial actions armed by the RAS controller is to automatically and immediately reduce the Gates to Panoche line flow to a lower value. The resulting line flow is determined based on the amount of remedial action that can be activated and the effectiveness of each remedial action in reducing the line flow. Starting with the reduced line current that exist after the initial automatic remedial actions, a current vs. time curve that includes the effect of the Diablo Canyon ramp-down is constructed and the corresponding temperature function calculated (Fig. 2).

During the initial pass, the temperature function represents present power transfer conditions. If the maximum temperature calculated is less than the criterion 100 C, then the Path 15 thermal rating for the Gates-Panoche line/DLO limitation is greater than the present Path 15 flow. By defining a somewhat higher transfer condition and recalculating the temperature function for this higher transfer, a new maximum temperature is found that can be compared to the 100 C, criterion. After a few iterations and appropriate interpolation or extrapolation, the transfer that yields a maximum temperature of precisely 100 C is determined. This is the Path 15 thermal rating

Utilization and Benefits of Dynamic rating

The real time rating system described in this paper is designed to provide the operator with the maximum allowable Path 15 flow as limited by the maximum allowable conductor temperature on the Gates-Panoche 230 kV line for the simultaneous outage of the two 500 kV lines on Path 15. This rating, which is updated every 30 seconds, reflects in real time changes to the following significant variables:

1. Ambient temperature
2. Solar radiation
3. Effective wind speed
4. Load, generation and transmission flow patterns
5. The current MW value of loads and generation armed to trip for the contingency
6. The availability of Diablo Canyon ramp down
7. Switching of significant lines or transformers

In addition, the dynamic rating procedure provides the operator with the higher Path rating that would be obtainable if all available remedial actions were armed.